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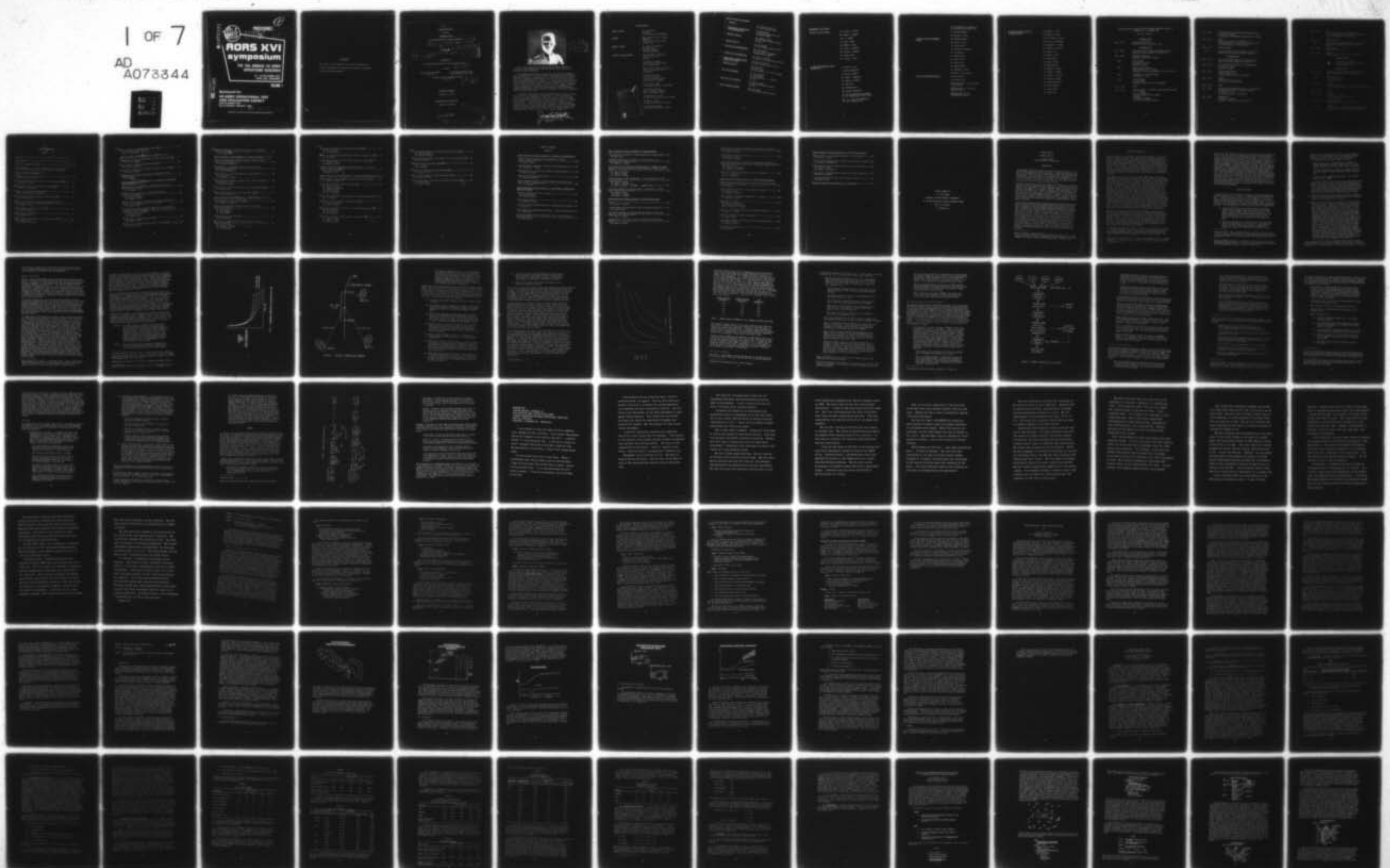

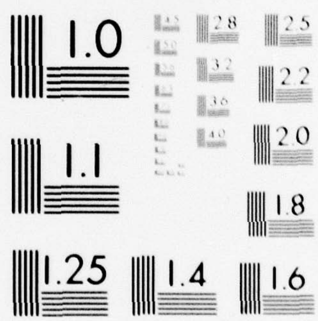

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PROCEEDINGS

AORS XVI symposium

THE 16th ANNUAL US ARMY OPERATIONS RESEARCH

12 - 14 OCTOBER 1977
FORT LEE, VIRGINIA

VOLUME I

Sponsored by:

US ARMY OPERATIONAL TEST AND EVALUATION AGENCY
5600 COLUMBIA PIKE
FALLS CHURCH, VIRGINIA 22041

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(6)

FINAL PROCEEDINGS

OF THE

SIXTEENTH ANNUAL

US ARMY OPERATIONS RESEARCH SYMPOSIUM (16th).

held 12-14 October 1977,

Fort Lee Virginia.

VOLUME ~~ONE~~ I.

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The US Army Operational Test and Evaluation Agency considers it a privilege to have sponsored the Sixteenth Annual United States Army Operations Research Symposium.

The thoughts shared in the presentations made during the symposium were very supportive of this year's theme "Operations Research Support of the Army of the 80's -- Looking Ahead." It was pointed out very clearly during the symposium that the key to success for the Army of the future lies in the productivity of its people. It is the people who must find the ways and means to minimize the number and the impact of the hard choices the Army will face in the future. The Army of the 80's must be supported by good analytical techniques which assist the field commander in increasing productivity. I feel that participation in this symposium enhanced the development of the analytical techniques necessary to adequately support the Army of the 80's.

I express my appreciation to the personnel within my agency for planning, organizing and chairing the symposium, to the US Army Logistics Center, the US Army Quartermaster Center and Fort Lee, and the US Army Logistics Management Center who for the fourth consecutive year co-hosted this symposium. I especially thank General Walter T. Kerwin, Jr., Vice Chief of Staff, US Army; Dr. Seth Bonder, President, Vector Research Incorporated; Dr. Daniel McDonald, Vice President for Technical Programs, the BDM Corporation; other distinguished speakers, special session chairpersons, the many contributors of papers, and all support personnel who contributed their time and energies to the success of AORS XVI.

JULIUS W. BECTON, JR.
Major General, US Army
Commanding

ACKNOWLEDGEMENTS

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	Dr. Marvin E. Lasser Chief Scientist and Director of US Army Research
	Major General Ernest D. Peixotto Director of Materiel Plans and Programs
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	Dr. Roland V. Tiede Science Applications, Incorporated
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SIXTEENTH ANNUAL US ARMY OPERATIONS RESEARCH SYMPOSIUM (AORS) XVI
12 OCTOBER 1977 - 14 OCTOBER 1977

Fort Lee, Virginia

11 October 1977

1800 - 2100	SOCIAL AND REGISTRATION Lee Room of Fort Lee Officers' Club

12 October 1977

0730 - 0815	AORS Shuttle Buses Depart AORS Parking Lot and Bachelor Officers' Quarters for Bunker Hall
0745 - 0845	REGISTRATION (Make-Up) Location: Bunker Hall, Room 241
0845	CALL TO ORDER Mr. Walter W. Hollis Symposium Chairman
0850	WELCOME (for Co-Hosts) Major General Fred C. Sheffey Commander, US Army Quartermaster Center and Fort Lee
0900	INTRODUCTION OF KEYNOTE SPEAKER Mr. Walter W. Hollis
0905	KEYNOTE ADDRESS Dr. Seth Bonder President, Vector Research Incorporated
0950 - 1015	BREAK
1015 - 1050	STATIC ANALYSIS - AN ANSWER TO THE COMPLEXITY CRISIS Mr. N.G. Asbed Mr. L.S. Steenrod US Army Concepts Analysis Agency Addendum Mr. Seymour Deitchman Institute for Defense Analysis

1050 - 1135	A TIME STEP MODEL FOR REPLAYING SIMULATED BATTLES Dr. Marion R. Bryson US Army Combat Developments Experimentation Command
1135 - 1300	LUNCH Bunker Hall or Fort Lee Officers' Club Bus Transportation - Main Entrance of Bunker Hall to Fort Lee Officers' Club and Return
1300 - 1700	SPECIAL SESSIONS
1710	Buses Depart Main Entrance Bunker Hall for AORS Parking Lot and Bachelor Officers' Quarters

<u>13 October 1977</u>

0715 - 0745	AORS Shuttle Buses Depart AORS Parking Lot and Bachelor Officers' Quarters for Bunker Hall
0800 - 0815	CALL TO ORDER AND ADMINISTRATIVE ANNOUNCEMENTS Mr. Walter W. Hollis Symposium Chairman
0815 - 0900	DIVISION RESTRUCTURING Colonel Donald S. Pihl US Army Training and Doctrine Command
0900 - 0945	ADDRESS General Walter T. Kerwin, Jr. Vice Chief of Staff, US Army
0945 - 1010	BREAK
1010 - 1055	REPORT ON OUR CONTRACTURAL REVIEW OF THE QUALITATIVE AND QUANTITATIVE VALUE OF TACTICAL MOBILITY Dr. Roland V. Tiede Science Applications, Incorporated
1055 - 1140	AFFORDABILITY MG Ernest D. Peixotto Director of Materiel Plans and Programs

1140 - 1300	LUNCH Bunker Hall or Fort Lee Officers' Club Bus Transportation - Main Entrance of Bunker Hall to Fort Lee Officers' Club and Return
1300 - 1700	SPECIAL SESSIONS
1710	Buses Depart Main Entrance Bunker Hall for AORS Parking Lot and Bachelor Officers' Quarters
1830 - 1930	SOCIAL HOUR Fort Lee Officers' Club
1930 - 2130	BANQUET Main Ballroom at the Fort Lee Officers' Club

BANQUET SPEAKER

Dr. Daniel F. McDonald
Vice President, Technical Programs
The BDM Corporation

14 October 1977

0715 - 0745	AORS Shuttle Buses Depart AORS Parking Lot and Bachelor Officers' Quarters for Bunker Hall
0800	CALL TO ORDER Mr. Walter W. Hollis Symposium Chairman
0815 - 0915	ADDRESS Dr. David A. Schrady Dean of Academic Planning, Naval Postgraduate School
0915 - 0940	BREAK
0940 - 1015	ADDRESS Dr. Marvin E. Lasser Chief Scientist of the US Army
1015 - 1030	CLOSING REMARKS Major General Julius W. Becton, Jr.
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KEYNOTE ADDRESS BY

DR. SETH BONDER

PRESIDENT, VECTOR RESEARCH, INCORPORATED

TO THE ARMY OPERATIONS RESEARCH SYMPOSIUM (AORS)

FORT LEE, VIRGINIA

12 OCTOBER 1977

Keynote Address

CHANGING ARMY OR

Dr. Seth Bonder
Vector Research, Incorporated

INTRODUCTION

I am pleased to have been invited to present the keynote address at this the 16th Army Operations Research Symposium. I have participated in many AORS since attending my first in 1963 (the 2nd AORS) and have fond memories of them. It was reassuring to review the list of attendees at the 2nd AORS and observe that some of the captains are now generals, and many of the participants (who were not young then) are still alive and some actively practicing in military and other OR areas.

When Walt invited me to present this address, he asked that I keynote the symposium theme by suggesting useful directions for Army OR over the next decade or so. Generally, I consider symposium themes as necessary administrative requirements to be ignored. However, after some thought, I was convinced that there are, in fact, some changes in direction required if OR is to exist as a professional activity in the Army. I am of the impression that the Army OR community suffers a credibility gap in the eyes of its military leaders, and that the work we do is accepted for legislated reasons but not particularly respected or deemed necessary for the good of the Army.

In last year's keynote address,[1] Dave Hardison suggested we had problems with many senior military and defense managers but, following his own advice, presented a simplified description of the problem and its solution. Although I am sure that complex approaches contribute to the problem and that simpler presentations and models would help, nevertheless that prescription only serves to suppress the disease symptom without addressing its cause. Rather, I believe the problem is that we do too much systems analysis (or more precisely, system evaluations) which (a) is not wanted by military managers, (b) is not believable by them, (c) has no demonstrable validity, and (d) most importantly, provides none of the necessary feedback or substantiation to us or them of its military contribution. I want to devote a few moments to providing some historical perspective to focus this point and then will spend the remainder of the address presenting a number of example topics which I believe should be pursued over the next 10 to 15 years by the Army OR community.

---

[1]David C. Hardison, Keynote Address, *Proceedings Fifteenth Annual US Army Operations Research Symposium,* (Sponsored by the US Training and Doctrine Command, Fort Monroe, Virginia, 26-29 October 1976), Volume 1, p.4.

HISTORICAL PERSPECTIVE

Operations research in World War II was primarily analyses of existing military systems to improve their operating effectiveness and/or efficiency. The availability of operating systems and ongoing military activities facilitated the gathering of data on systems' capabilities and effectiveness, enemy characteristics and tactics, and environmental factors for use in studies. The success of these activities is recorded in history. It was a period of glamorous contributions to the military via analysis of the use of gun laying radars, bombing tactics, convoy structures, and target search procedures, to mention but a few. The work was performed by innovative scientists whose contributions were needed and respected.

After the war and during most of the 1950s, emphasis was on military-requirements studies as the individual services redefined and negotiated their roles and missions in the defense establishment. In the late 1950s and 1960s, there was a shift to problems of broader scope and complexity such as the development of weapon systems, force compositions, and, in general, planning for future programs and the next generation military systems. The term "systems analysis" was coined by Rand economists to describe the cost-effectiveness study activities associated with this long-range planning. The move toward more centralized management and defense decision-making in 1961 required the military services to learn and use systems analysis as a means of quantitatively justifying their share of the defense budget. In contrast to the operations research of World War II which was a data-based scientific activity, the extended decision horizons of five, ten, and twenty years associated with long range planning preclude data-related efforts in many military areas and cause systems analysis to be an intellectual activity rather than a scientific one.[1] It is an intellectual art used in making necessary and, at times, useful predictions in problem areas where measurements, data collections, experiments, and verification are difficult and at times impossible.

Because of the emphasis on prediction and the need to justify requests for resources quantitatively in the 1960s, the Army developed many war games and models to generate cost-effectiveness numbers to support development proposals. In conflicts with OSD-SA, the services usually lost, because, in the absence of data, the OSD analysts made up the analysis rules (i.e., assumptions, threat levels, input data) but usually after the fact. Thus, the Army OR analyst did not perform analyses to determine what was need but rather conducted numerical evaluations as the Army's vehicle to advocate what was wanted.

If the 1960s instigated this tyranny of numbers, the 1970s has formalized it. The weapon system acquisition process was institutionalized into a long complex management system. The adversary process has been legislated throughout the Defense Department via DoD Directive 5000.1. The

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[1]Seth Bonder, "Systems Analysis: A Purely Intellectual Activity," Keynote Address, *Proceedings Twenty-fifth Military Operations Symposium* (U), 16 June 1970, pp. 3-9.

Army has met this challenge by legislating (via AR 1000-1 and TRADOC Regulation 11-8) that COEAs be conducted for most materiel development proframs at various points in the development process. The studies have become increasingly complex to prove, by the sheer weight of numbers, that system A is better than system B. A significant amount of resources at Army OR organizations such as TRASANA, CAA, and the TRADOC schools are devoted to production, job-shop-like COEA activities. Approximately 15 major program COEAs or updates and about 30 subsystem ones are conducted each year. I concur with Dave's contention last year that they belabor needless detail and overlook key questions, and with General DePuy's[1] belief that they needlessly prolong and complicate the development process. More importantly, they do not contribute any knowledge about military activities (I cannot remember when last I saw a bright experimental hypothesis emerge from such studies) and have the effect of encouraging analysts not to think. I am of the impression that senior military officers view much of the OR community, perhaps with justification, as a necessary modeling/COEA activity and not a valuable analysis asset that can identify important problems, solve them, and contribute to the inventory of military knowledge.

FUTURE DIRECTIONS

I strongly believe that if emphasis continues on these job-shop-like activities, OR/SA will cease to exist as a meaningful activity within the Army. I think the time is right to shift the emphasis of OR activity from the long range planning issue of "what is needed for the future" to address the more operational one of "how to use what we have." That is, we should focus our efforts on research on operations rather than systems analysis. This recommendation is based on the following considerations.

(1) Serious questions are being raised,[2] both in the defense community and elsewhere, regarding the ability to do meaningful, precise, quantitative, cost-effectiveness or cost-benefit analyses on development programs whose product will not be realized for 5, 10, or 15 years, especially the ability to characterize the undertainties associated with them.

(2) There will continue to be a growing need for and concomitant payoff from the analysis and solution of a large number of current and future operational problems. Stimulated by advances in science and technology, and hopefully in part

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[1]General William E. DePuy, Welcome Address, *Proceedings Fifteenth Annual US Army Operations Research Symposium*, (Sponsored by the US Army Training and Doctrine Command, Fort Monroe, Virginia, 26-29 October 1976), Vol. 1, p. 21.

[2]See, for example, *Versatility: An Objective for Military Planning*, by Seth Bonder, Keynote Address, 37th Military Operations Research Symposium, (US Army Air Defense, Fort Bliss, Texas, 22 June 1976).

rationalized by DoD planning, the Army is in the process of modernizing its operational forces. Between now and 1985, the Army will field (or have available in prorotype) a broad spectrum of new materiel systems including:

- Combat Systems: XM-1, a MICV type IFC, armored and mobile TOW, DRAGON, ILAW, AAH, Copperhead, GSRS, UTTAS, STINGER, SAM-D, and possibly enhanced radiation warheads;
- Intelligence/EW Systems: SOTAS, ALR, TACELIS, AGTELIS, QUICK FIX, MULTEWS, TACJAM, LEFOX GREY, EWIOCS, and CACS; and
- Command, Control, Communication Systems: TOS, TACFIRE, Missile Minder, INTACS.

These systems reflect major advances in technology which, when compared to systems currently in the hands of the troops, I believe will come as a cultural shock to the operating units. This is especially true in the intelligence, EW, and C^3 areas. I am convinced that the Army does not now understand how to employ most of these systems effectively, much less how to operate during the multi-year transition period to them.

(3) Defense budget constraints coupled with the current modernization will preclude the Army from procuring any significant number of new systems for 20 to 25 years.

(4) There will exist shortly a near parallel situation in the field to that which prevailed in World War II for the operations researchers. There will be a rapid introduction of new, complex military technology into the hands of forces lacking any experience in its use. The *raison d'etre* of the ops analyst in World War II was as a principal translator of technology into effective operational employment. Although a war does not now exist to provide actual combat experience, the many real exercises in Europe (such as REFORGER) and the US, coupled with the use of computerized combat modeling technology, can provide an environment for simulated but very credible large unit operational experiences. Instrumented facilities such as CDEC can provide valuable data on the dynamics within small unit actions. Thus, I believe there exists an opportunity for military operations researchers, like their progenitors in World War II, to develop a detailed, data based understanding and knowledge of the dynamics of military processes, leading to the more effective employment of military systems. Of professional importance, it will provide an environment in which analytically derived solutions can be tested to provide relatively quick feedback on their efficacy.

I have suggested that research on operations rather than long range planning systems analysis should be emphasized by the Army OR community over the next 10 - 15 year period. To illustrate the nature of this work,

I will discuss a sample set of operational issues which I think OR can assist in quantitatively addressing, and which would provide a significant and welcome contribution to military operations.

Maneuver Unit Tactics

Tactics is the principal means by which the Army will win the next land battle. This will be increasingly true over the next decade or two because the Army is engaged in a large modernization with sophsiticated weaponry. As noted by Generals Starry and Hunt[1]: "Far sighted leaders have perceived that this [modernization] will require new organizations as well as new tactics." Additionally, both sides will be employing technology more similar than different and rewards will go to those who learn to use the technology to advantage. Although some thought and progress has been made in TRADOC and by operational commanders in Europe, I contend there is more art than science and that more understanding and knowledge regarding battlefield dynamics are needed.

Let me first consider the large unit division-corps defensive tactics. Intelligence suggests that one of the Soviets' attack options is the breakthrough strategy derived from the earlier German Blitzkrieg concept. Outnumbering the NATO forces 3:1 on the average, their first move advantage can be used to concentrate forces to create force ratios of five or six to one at selected points along the FEBA. The tactic is to attack with mass and velocity at these points to cause penetrations and breakthroughs that can be reinforced. Such a result would be a failure of the defending anti-armor forces.

To defend against the breakthrough strategy, FM 100-5 revised the concept of a light covering force defense. The basic precept of this revised defense is that the covering force will deceive the enemy into thinking he is engaging the main defensive body and accordingly deploy his maneuver and fire support units to begin his main lines of attack. Intelligence assets will then identify the threat's points of concentration in sufficient time to deploy a main line of defense to block these penetration attempts by restoring a 3:1 force ratio. I have not seen any hard dynamic force analysis that demonstrates the efficacy of this tactic. I am not convinced that a 3:1 force ratio guarantees a successful defense. I do not believe that a covering force can deceive the opponent to deploy, nor have I seen evidence that our intelligence assets will provide timely combat information to deploy on just the right penetration avenues. In fact, I have seen evidence to the contrary in the recent CARBON EDGE REFORGER exercise. Covering forces did not cause Orange to deploy for concentrated attacks, and the intelligence system was ineffective early in the campaign. It would appear that the covering force tactic as described in FM 100-5 still leads to one main line of defense which can be attacked with concentrations at selected points or, worse, to pockets of heavy anti-armor defenses which get bypassed by more distributed threat deployments. There clearly exists the need to develop better tactical concepts, based on field measurement, experimentation, and dynamic force analysis, that can deter, and if necessary, defeat the massed breakthrough attack strategy.

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[1]Major General Ira A. Hunt, Jr., and General Donn A. Starry, "The Role of Armor in Modern Battle (U)," to be published in a special issue of the *Journal of Defense Research* entitled "Armored Fighting Vehicles."

It appears from past analyses that for a successful defense, significant attrition of the threat must occur while trading ground prior to reaching a single "decisive battle" defensive position. General Starry implemented this principal in the V Corps area with a heavy covering force defense -- a heavy deployment of battalions near the border to engage the enemy immediately and extract significant attrition as they fall back to the MLD east of the Vogelsberg hill mass.[1] Because of the limited favorable defense territory, the forces appear to be almost uniformly distributed over the area for battalion-sized engagements and a limited trading of ground for enemy attrition will occur.

Clearly, there must be other tactical principles that might lead to improved tactics for defense against the massed breakthrough attack strategy. For example, it is conjectured that in a single battalion- or company-sized defensive engagement, the instantaneous *exchange ratio*[2] as a function of battle time is as depicted in figure 1. The instantaneous exchange ratio is very high and relatively independent of the force ratio (and particularly of threat size) early in the battle because of concealment and first shot advantages accrued the defender. The instantaneous exchange ratio advantage moves to the attacker as the forces become decisively engaged, because more attackers find and engage targets and the concentration and saturation phenomena come into play for the attacker.

In terrains that permit it, this conjecture (if valid) suggests that an in depth use of a large number of company and below, brief, direct fire engagements or ambushes may be an effective tactic. The structure of the typical, company-sized ambush in a killing zone is shown in figure 2. In brainstorming sessions[3] at the DUSA (OR) office two years ago, we envisioned that such a campaign might occur in two phases.

Phase I: This phase involves a somewhat constant density of small mechanized antitank teams who engage threat forces in carefully selected (and perhaps preprepared) terrain locations. They operate at the very high, essentially force ratio independent, part of the instantaneous exchange ratio curves by firing a small number of rounds and immediately withdrawing before suffering any attrition. The withdrawal is made to another engagement site, passing through a similar site occupied by another AT team.

Phase II: This phase continues the sequence of engagements of phase I; however, increasing amounts of enemy attrition are to be obtained per unit of ground traded at

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[1]For a description of this tactic see Lt. General Donn Starry's address, *Proceedings Fifteenth Annual US Army Operations Research Symposium*, (sponsored by the US Army Training and Doctrine Command, Fort Monroe, Virginia, 26-29 October 1976), Vol. 1, pp. 23-58

[2]Mathematically, the ratio of the rates of attacker and defender losses.

[3]See Seth Bonder, et al., *DUSA(OR) Memorandum for Record, subject: Anti-Armor Capabilities Study, Brainstorming Session (U)*, September 1975.

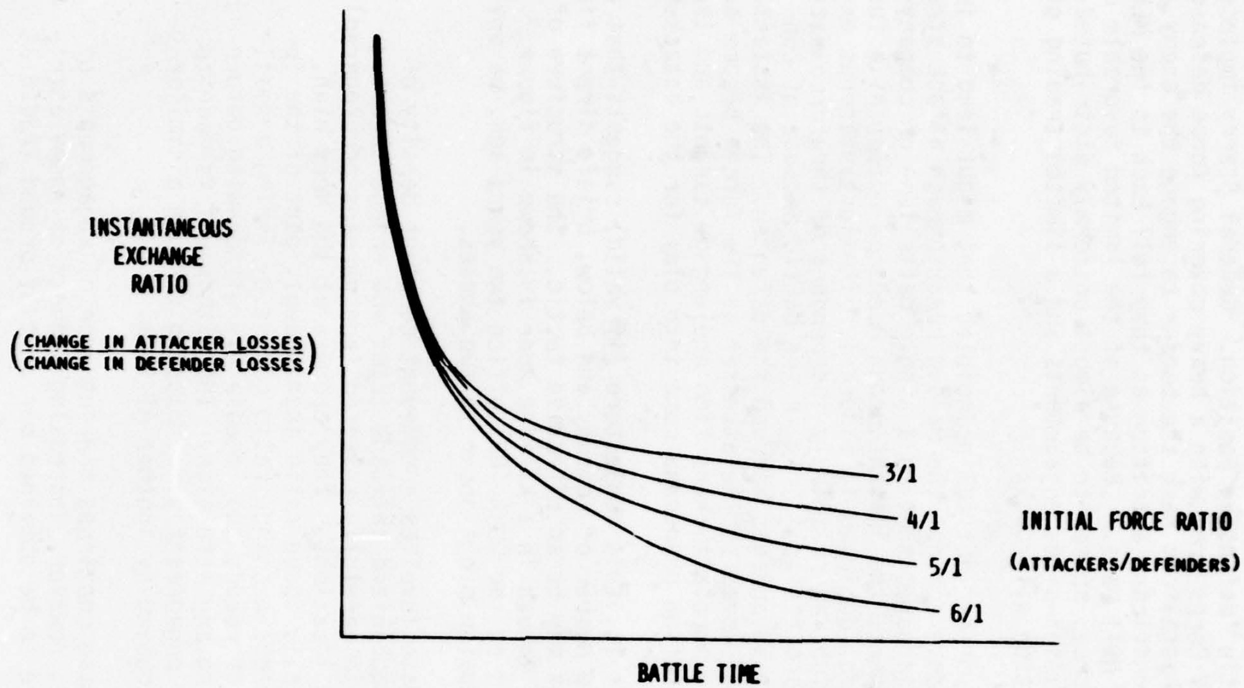

FIGURE 1: INSTANTANEOUS EXCHANGE RATIO AS A FUNCTION OF BATTLE TIME

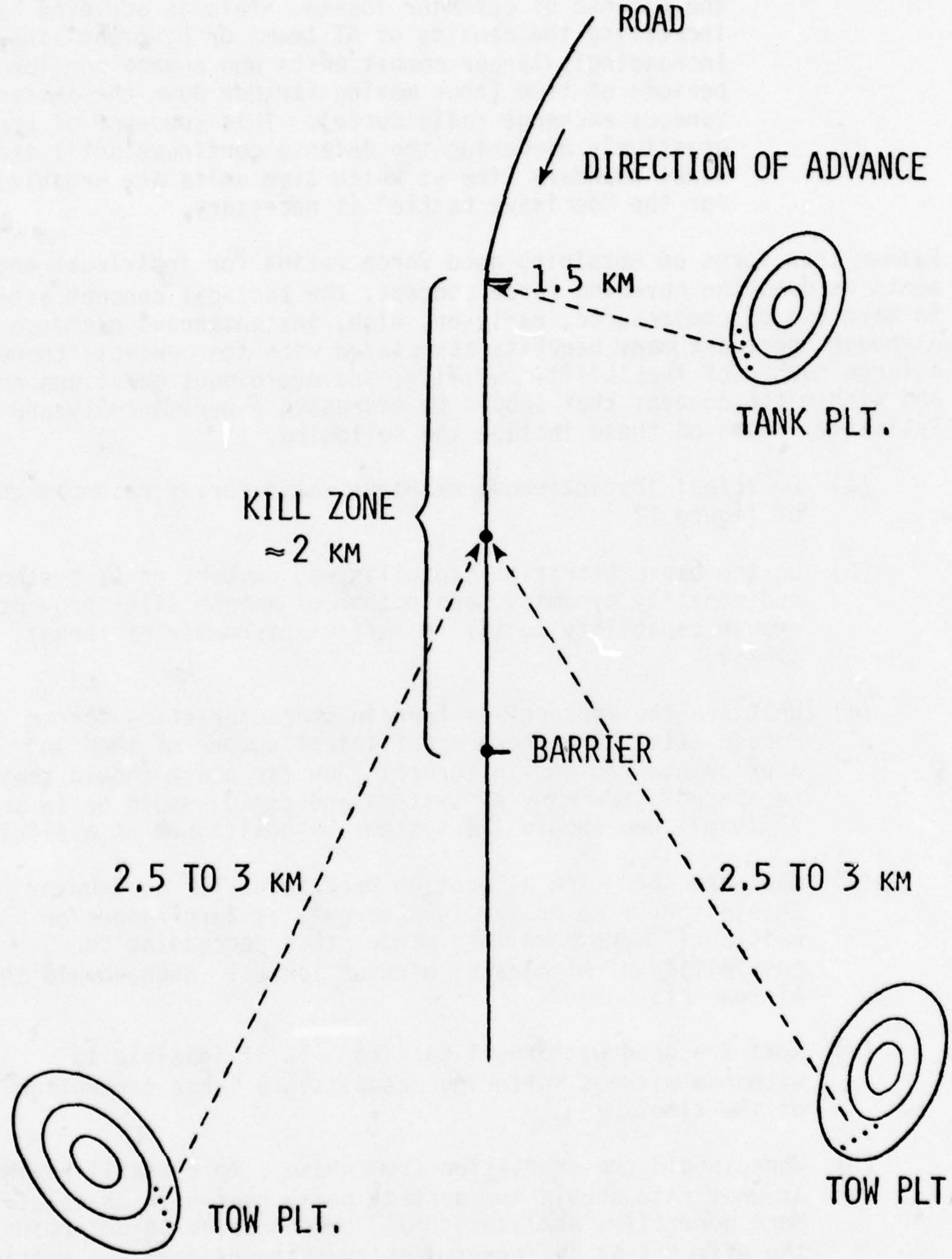

FIGURE 2: TYPICAL, COMPANY-SIZED AMBUSH

the expense of defender losses. This is achieved by increasing the density of AT teams or by organizing increasingly larger combat units who engage for longer periods of time (thus moving farther down the instantaneous exchange ratio curve). This sequence of progressively hardening the defense continues until the final boundary line at which time units are organized for the "decisive battle" if necessary.

Rather than focus on obtaining good force ratios for individual engagements as does the covering force concept, the tactical concept attempts to make use of conjectured, early-on, high, instantaneous exchange ratios. Although there are many benefits associated with the concept, there are a large number of feasibility, utility, and employment questions about and within the concept that should be addressed experimentally and analytically. Some of these include the following.

(a) Do actual instantaneous exchange ratio curves resemble those of figure 1?

(b) Do the basic attrition capabilities, numbers of AT systems and mobility dynamics, and number of ambush sites provide enough capability to kill a sufficient number of threat tanks?

(c) What are the appropriate terrain characteristics for an ambush site? Are there a sufficient number of them in appropriate regions in Europe? How far apart should they be spaced? How many AT systems and tanks should be in an AT team? How should the systems be positioned at a site?

(d) What are good fire allocation procedures for an ambush? Should they fire on the lead targets at long ranges or wait until more come into range, thus decreasing the possibility of withdrawal without losses? When should the AT team disengage?

(e) What are good withdrawal tactics? Is it feasible to withdraw without suffering casualties a large percentage of the time?

(f) When should the transition from phase I to phase II begin? At what rate should the density be increased in phase II? More generally, analyses should be conducted to determine the effect that different density patterns over the battlefield and different redeployment tactics have on the dynamics of the battle.

(g) Should the increased density in phase II be accomplished by increasing the density of ambushes or the organization of unit wave defenses of increasing numbers? When should AT teams from other parts of the battlefield be used to increase the density?

(h) The dynamic density defense concept would create command-control problems. How should the units be controlled? What logistics, communications, materiel, and discipline requirements are necessary to implement the concept?

(i) What are the accuracy and response requirements for artillery to support the concept?

This is but one additional tactical concept that might be analyzed and tested in a search for an effective defense against a Soviet massed breakthrough attack strategy. The feasibility and utility of others can and should be explored. For example, is the counterattack an effective defense mechanism to slow the momentum of the attack? Although it appeared to work well for Blue in REFORGER, we must have more understanding as to where, when, and how it should be conducted. Will we, in fact, be able to counterattack with the new generation of weapon systems which are heavily defense oriented?

I have no doubt that the Soviets devote significant analysis efforts to understanding tactical concepts of attack. In their forthcoming paper, Generals Starry and Hunt[1] indicate that the Soviets are willing to accept heavy tank losses in using velocity and mass to achieve a successful attack. It would not surprise me that the Soviets understand tactics better than we do in that velocity and mass may be the *best* way to *reduce* losses if you wish to attack. Figure 3 suggests that this might be true in some particular tank force battles. The relationships used to derive the curves consider the weapon system capabilities, their range dependencies, number of forces, etc. The curves suggest that increasing the attack velocity increases the number of survivors but with decreasing marginal returns. For a fixed attack velocity, higher initial force ratios conserve attackers. In essence, speed and force concentration are good ways to saturate a defender's retaliatory capability. What is the defense analog of velocity and mass for an attack?

Let me next note a few operational issues regarding maneuver tactics for small unit engagements. One would expect that with all the study and analysis performed on battalion- and company-sized engagements for weapons procurement we would have an in-depth understanding of small unit tactical dynamics. Yet there are many operational issues that I do not believe we understand. For example, one would think military officers would have some common understanding as to how to task organize a battalion for effective defense of an objective. We ran an experiment with 30 infantry offi-crrs who were asked to organize a fixed set of infantry battalion resources into subunits for three different defensive situations. We obtained 46 significantly distinct defense task organizations. I am not implying that this result is good or bad, only that it is diverse, which suggests that the military do not as yet understand or have definitive guidelines on organization for battlaion level defenses. Can we help develop this understanding?

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[1]Hunt and Starry, *loc. cit.*

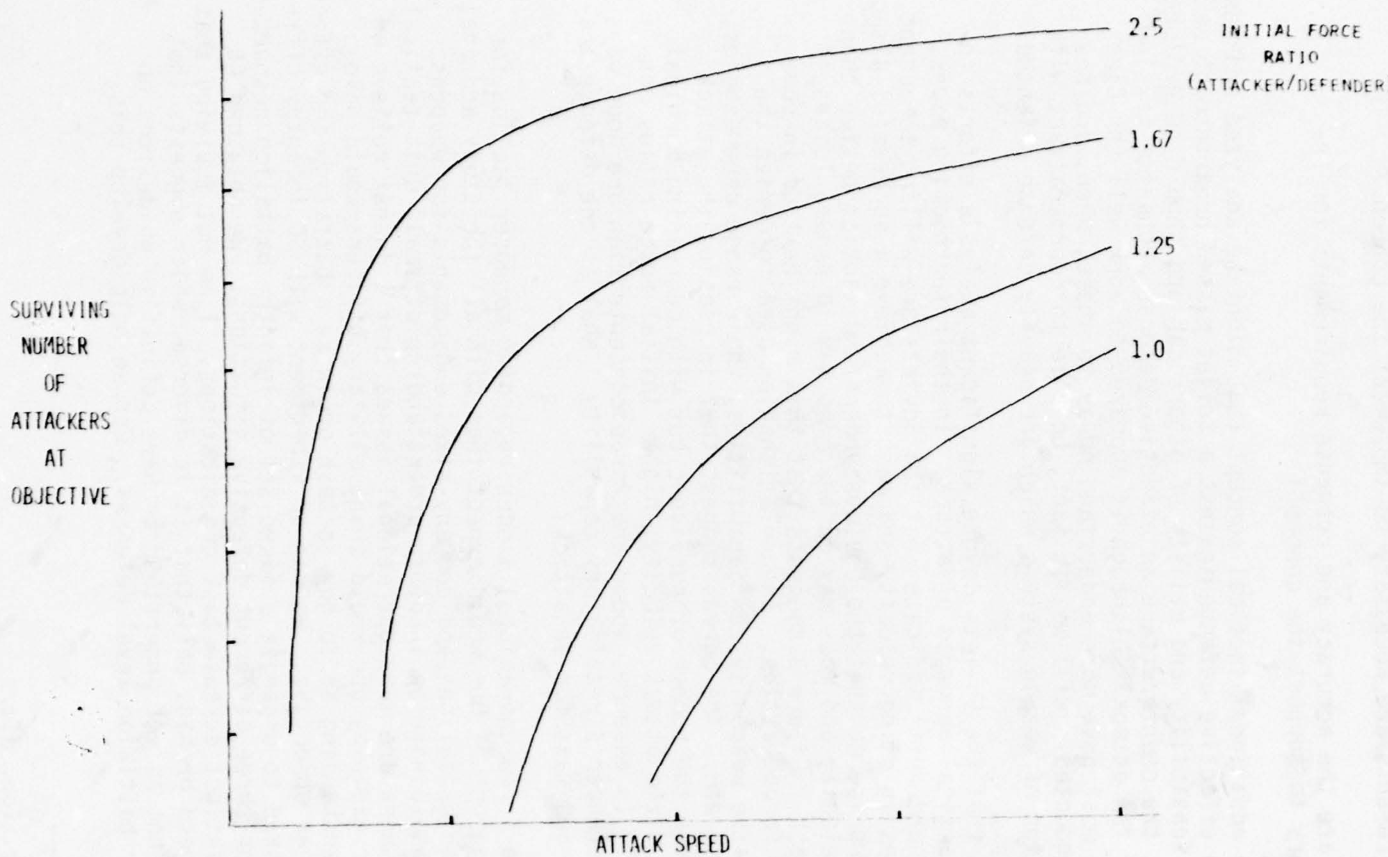

FIGURE 3: SURVIVING NUMBER OF ATTACKERS AS A FUNCTION OF ATTACK SPEED

The terrain line of sight (LOS) is recognized as having a significant impact on the effectiveness of the coming generation of direct fire weapon systems such as TOW, XM-1, DRAGON, and others intended for use in small unit engagements. Yet I think the Army does not understand the subtle interactions between the terrain LOS characteristics and the tactics for employing these systems. In a study about two years ago, we asked military analysts to select five likely, company-sized defensive positions in a terrain that appeared to have relatively homogeneous LOS characteristics and to design the defense and assault tactics for each. Our hypothesis was that, for a fixed set of attack and defense resources, the estimated combat results would be about the same for each of the engagements because the military tacticians indicated that the terrain LOS conditions were very similar for each, and they had designed the tactics to use the terrain effectively. The tacticians concurred. Table 1 depicts some of the results.

AVERAGE ATTACKER SURVIVORS[1]	AVERAGE DEFENDER SURVIVORS[1]	WIN PROBABILITY
6.9	2.5	.43
7.2	1.8	.08
6.0	6.0	1.00
5.0	4.5	.95
5.6	5.5	.98

TABLE 1: SAMPLE RESULTS OF COMBAT ON FIVE "SIMILAR" DEFENSIVE POSITIONS

The variance in combat results is very high, suggesting that either the model used to generate the results is incorrect or the terrain-tactics interactions are not well understood. A follow-on study indicated that a majority of this variability is due to attacker coordination differences. Clearly, this is an area which is of significant operational importance and one that is amenable to experimental and analytic study.

I think I need not emphasize the importance of understanding the tactical implications and use of smoke in small unit actions. How should we operate when the enemy employs smoke in an assault? Will it reduce the time we have to service a fixed number of attackers? If so, how should we change our defense tactics until technological fixes are developed? How should we operate if the enemy uses smoke when we assault? How should we use smoke in the defense? In the attack?

Fire Support Procedures

There exist a large number of issues and questions in the operational use of artillery, attack, helicopter, and CAS that can and need be addressed

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[1]Fifteen initial attackers and six initial defenders.

to enhance the delivery of fire support fires. In the interest of brevity, I will note but a few interrelated ones without much elaboration.

- Dynamic Allocation of Supporting Fires: It is anticipated that increased target acquisition capability in the form of SOTAS, ALR, and many SIGINT systems will result in a significant increase in the number of high priority targets and thus requested fires.

  - How can we best coordinate the use of artillery, CAS, and attack helicopters? Who should be assigned what targets and when?

  - How should requests for fire be satisfied when there is a saturated fire request queue?

  - Can we continue to guarantee artillery fires to the brigades, given the limited number of tubes available?

  - When should a threat maneuver unit be targeted with fire support fires? When engaged? Enroute to the front? Before or after crossing a barrier?

  - When should artillery be used against threat maneuver units versus counterbattery fire?

- How can we coordinate the use of AH and CAS fire support with the suppression (both fire and EW) of threat air defense artillery?

- What is an appropriate way to trade off the coverage and survivability of artillery? Forward deployment increases their coverage at the expense of survivability, while deployment further back from the FEBA reverses this tradeoff.

- How can the fire support element make more effective use of SOTAS? In the first week of the recent REFORGER exercise, SOTAS was used principally by the G-2 section for OB estimation and only minimally as a target acquisition source for dynamic allocation of artillery fires.

- Should the number of tubes in an artillery battery be increased? In the division artillery with 66 tubes,[1] there is an overall average of 32 people per tube but only 10 are required to fire a tube.[2] What are the operational trade offs with spreading the management personnel costs over more tubes? Could the number of tubes per battery be increased without adding personnel to the division artillery?

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[1]Three 155 mm battalions with 3 batteries of 6 tubes each and one 8" battalion with 4 tubes per battery.

[2]There are approximatley 2100 people in the division artillery, about 1400 of whom are management. Each battery has about 100 people, about 40 of whom are management.

- How can the range capability of Copperhead be exploited beyond the range of targets in line of sight with the forward observer and the GLD? Copperhead appears to be a losing competitor against direct fire systems as a tank killer in the 0 - 3 km region. Is is feasible to use stay-behind forces? RPVs?

- What is an appropriate basic load for an artillery battery considering the proliferation of ammunition types that are and will be available?[1] How should this load structure change with projected artillery missions?

- What is the best way to employ FASCAM? How should it be used? Should it be deployed in front of adversary forces or on top of them? What size area should be covered?

Intelligence/Electronic Warfare Procedures

The need to develop effective operational procedures in the intelligence and electronic warfare areas I believe exceeds that of maneuver unit tactics and fire support procedures because (a) the forthcoming generation of technologically complex IMAGERY, ELINT, and COMINT intelligence systems are expected to provide a "fire hose" of near real-time data on the threat, (b) SIGINT and EW systems are now organic to the units and are the responsibility of the operating commanders, and (c) effectively employed EW capabilities can provide a new dimension of combat power for the operating forces. Yet, we have relatively little experience in how to employ these systems. I am not convinced we know how to employ even the generation of primitive systems now fielded. Let me cite but a few areas where operational support is needed.

- G-2 Operations: Figure 4 provides a schematic view of the roles and functions of G-2 operations. The first processing function is an integrative one that assimilates all source collection reports to produce continual estimates of enemy order of battle for use by the operations staff. The second processing function is an analysis one that provides forecasts of alternative enemy capabilities, his likely intention, and its associated vulnerabilities. This information is developed to support tactical planning and control for the next period of the campaign. Finally, there is the function of developing plans to manage the collection assets. Operational assistance is needed on the following issues/questions.

  - Can we improve the information flows within and between the G-2 production and operations activities?

  - What is an effective means of integrating the many different time-based reports to produce best estimates of enemy order of battle (OB)? Must we produce OB enemy unit identifications or would knowledge of where threat forces are located suffice?

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[1]High explosive, white phosphorous, Copperhead, FASCAM, etc.

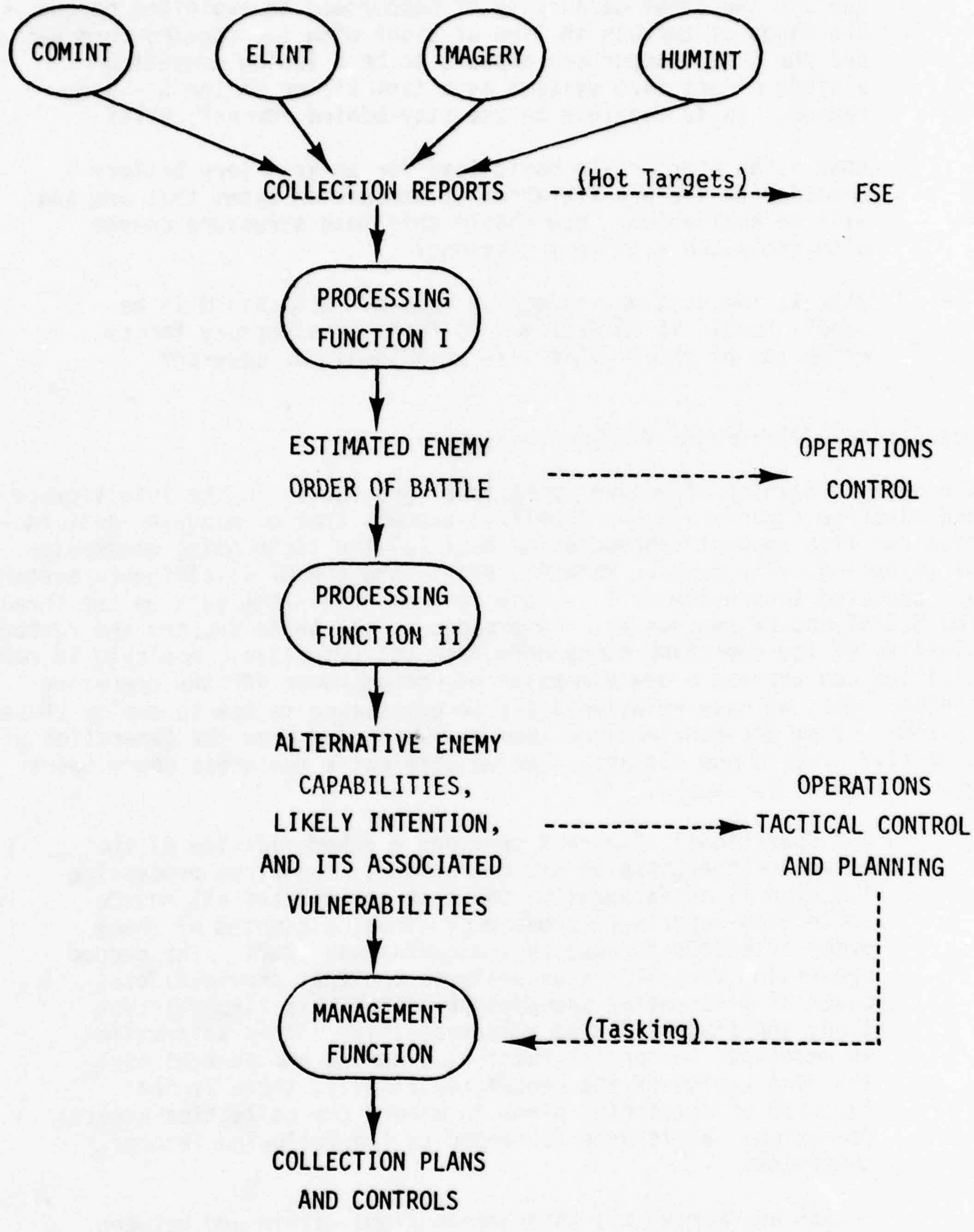

FIGURE 4: SCHEMATIC STRUCTURE OF G-2 FUNCTIONS

- How should the analysis function to estimate alternative enemy capabilities and select his likely intention be performed? Recognizing that this is a difficult cognitive process, clearly we can do better than the current procedure of staring at a large number of static OB guesses on a map!

- How should the collection plan for the next period of the campaign be designed to develop more evidence to support (or alter) the OB and enemy intention estimates? What are effective real time procedures to control the collection assets during their missions?

- How should the corps/division intelligence system coordinate and exchange information with the Army EAC, the Air Force, and other NATO nations to provide a common perception of the battlefield?

- How can a tactical intelligence transient be avoided between peacetime and wartime capabilities? In the anticipated short, fast-moving campaign, the operating commanders cannot wait 3 - 4 days for the intelligence system to provide useful information. Are there precedures which can provide for the survivability of tactical intelligence linguists/analysts and still insure effective utilization of this scarce resource?

- Where should jamming assets be used? Against what nets? When should jamming be employed in a defensive operation? An offensive one? What are effective procedures to employ automatic jamming of high priority frequencies?

- What is an effective way of trading off jamming and other means of servicing targets? When is it appropriate to collect versus jam, or deceive versus jam? Should an acquired threat ALR be jammed or destroyed?

- What are effective ways to search for targets using COMINT systems? Is it necessary to have unit identity information to extract useful information? What are effective means of maintaining a technical data base?

C^2 Procedures/Organization

The Army has had research programs in command and control and related automation systems for almost two decades starting with the CCIS study in 1958, field exercise CARDINAL, the DEVTOS in Europe and at MASSTER, SIMTOS at ARI, the IACS concept and IBICS. In the last seven years there have been a plethora of tests and studies in this area; yet, there remain, speaking charitably, a few unresolved fundamental, procedural and organizational issues.

- What are reasonable operating procedures between the G-3 and G-2 sections that provide for effective use of intelligence information by the operations staff and appropriate tasking of the G-2 activity by them?

- Can a TOC be structured that will facilitate better interactions between the intelligence and operations activities? Perhaps the G-3/G-2 dichotomy only serves to perpetuate the existing apparent caste structure.

- How often should a division TOC be moved to avoid lengthy transfer of control to the TAC and still minimize targeting of the TOC? Can the tear-down and set-up procedures be improved? Should we have a main TOC and an austere TAC or two identical main command posts?

- What procedures and aids can be developed to utilize all the data planned to be incumbent in TOS? How should the TOS data base be purged?

- Do we understand the trade-off, feasibility, and utility issues associated with centralized versus decentralized command and control of the corps lower echelon units and assets? Which would be more advantageous if we do not develop an intelligence system that provides a common perception of the battlefield from corps to the battalion?

Communication Procedures

There are a number of Army communications operational problems -- both large and small -- that I think could profit from data-based operational analyses.

- Communication of C^2 and intelligence information is one of the European Command's major problems in that rarely seems to operate. Can we assist in making it work?

- How should the Army operate recognizing that the communication system may likely fail?

- How should single channel frequencies be allocated to minimize inter- and intra-net interference? What discipline can be used to minimize this interference?

- What procedures should be used when a net is being jammed?

- How should division C^2 communications be routed to reduce the likelihood of the TOC and TAC being targeted?

- What on/off procedures should be used to mitigate acquistion by threat SIGINT systems.

Nuclear Doctrine

Until very recently, studies on employment of tactical nuclear weapons considered the efficacy of the one-sided, US nuclear salvo against a Soviet conventional force using a massed breakthrough strategy. A recent dynamic,

two-sided force analysis of combined conventional/nuclear campaigns against a "granular" attack strategy[1] has suggested that there exist a large number of unanswered operational and doctrinal issues and debates regarding the employment of tactical nuclear weapons against both the breakthrough and granular attack strategies.

- How effective is the new TRADOC salvo doctrine which advocates firing at suspected maneuver unit target locations with the largest yield available within collateral damage constraints? How does this doctrine compare to the previous doctrine of firing only at confirmed locations of discrete targets? Would it be effective to fire as suspected locations of threat TNF elements?

- How should weapons in a pulse be allocated between and among TNF elements and maneuver units?

- What are good strategies for employing multiple pulses?

- How effective is the SHAPE doctrine of employing a small nuclear signal?

- Would it be effective to:

    (a) extend a single pulse beyond the 45 - 90 minutes currently planned?

    (b) use large pulses against TNF elements only and surgically attack maneuver units with tactical nuclear weapons as needed?

    (c) use nuclear forces to channel attackers into killing zones prepared by conventional forces or vice versa?

    (d) disrupt the enemy C^2 by high priority targeting of his C^2 elements, either in the initial or a subsequent pulse?

    (e) have some artillery tubes designated for nuclear fires only?

Logistics Policies

Logistics has traditionally been a main area in which the Army has performed more operationally-oriented studies than long range planning ones. I recall the activity of the RAC crew including Wiggins and Hoppes, who

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[1]The significant characteristic of the granular attack strategy is that the attacking forces are generally distributed both lateral., and in depth throughout the attack zone.

lived with units of the VII Army in Europe in the early 1960s and contributed significantly in a number of operational logistics problems. While the Army has performed a few data-based operational logistics studies, I believe we should do more on-line analysis in the field similar to the earlier RAC work. Although I am clearly not as knowledgeable as our hosts here at the Logistics Center, I would think we could make some significant contributions in (a) the retail inventory management system (reorder points, reorder frequency, echelon at which to store items, etc.), (b) developing a good data base for current and future system repair parts demand, (c) identifying supply point locations for anticipated campaign conditions, (d) addressing a host of readiness (major item availability) problems for specific units, (e) developing and practicing wartime replacement policies, and (f) addressing important ammunition replenishment and distribution problems.

Methodology

This address would not be complete unless I made a few comments regarding OR methodology. Two of my comments identify high priority methodology areas and the third concerns Dave Hardison's pitch last year for simple models and approaches.

(1) Methodology for the 1980s: To implement the ideas I have proposed today for OR emphasis in the next decade or two, methodology for using field exercises, CDEC-type tests, and simulation technology (war games, simulations, analytic models) in an interdependent and synergistic manner will have to be developed. This methodology will have to address issues of the following kind.

- How should simulation technology be used to guide data collection efforts? What data should be collected in field exercises? In CDEC type tests?

- What degree of measurement accuracy is needed?

- How can field exercise data be collected with sufficient accuracy and (a) not give rise to the Heisenberg measurement effect and (b) not detract from the main purpose of the exercise?

- How should field data be used to verify the models? What types of hypotheses should be tested? How should field data serve as a guide to model developments? Is it feasible to do overall model verification studies or should it be by major submodels?

- Is it technically advisable to simulate at some echelons and perform field exercises and tests at others or should measurement and simulation be performed at all levels?

(2) Interactive Campaign Modeling: I believe another high priority methodology area involves the development and use of interactive models (with appropriate output graphics) in which significant decisions in a campaign are made interactively by military decision makers. It is important to recognize that I am not suggesting the development of large war games (we've been there before) with large numbers of players for Blue, Red, and Control teams, but rather a small number of decision makers (perhaps 1, 2, or at most 3) for each side who interact with the model such that it can be run in real or preferably compressed time. Interactive models will provide a number of benefits:

- They will be deemed more credible by many in the DoD when used as analysis vehicles,
- They will provide a useful diagnostic tool because of the player interactions,
- They could be designed to serve as valuable training vehicles for military decision makers (e.g., division commander, G-2, G-3, etc.), and
- They will provide a means of collecting large amounts of data on decisions and concomitant engagement status variables which could be used to develop empirical decision making relationships for use in automated models.[1]

(3) Occam's Razor Revisited: In last year's keynote address, Dave Hardison denounced complex approaches and models and urged the community to strive for simplicity of relationships and trends, not the room full of numbers. I would add a caveat to that -- let the models be both simple and *right*! All too often because of the complexity of some of our models and their data requirements members of our community have developed and used simple, but clearly inadequate, models in important analyses. For example, CAA and the Armor School both have developed simple linear models of weapon effectiveness and performed linear analyses of tank systems with them.[2,3]

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[1]Rather than attempting to build phenomenological models of how military decision makers make decisions which I believe is a futile, unrealistic activity.

[2]US Army Concepts Analysis Agency, "Weapon Effectiveness Indices/Weighted Unit Values (WEI WUV)." (SECRET) Volume II, Basic Report (Study Report CAA-SR-73-18) April, 1974. Bethesda, Maryland.

[3]US Army Tank Special Study Group, "Tank Special Study Group Report." (SECRET) Headquarters, US Army Armor Center and Fort Knox. 17 April 1975. Fort Knox, Kentucky.

Yet, General Starry and General Hunt point out the major shortcomings of such models[1] and indicate that they cannot take into account the many important dynamics of warfare. Complex phenomena at times require complex descriptions. Adequate simple models of complex processes may take years to develop. In fact, a review of combat model developments over the past two decades in the US would indicate that we have been following a trajectory toward sophisticated but less complex (i.e., less cumbersome) models. This trend is shown in figure 5 for both small unit engagements (battalion and below) and the division-corps level. The general trend[2] is to move from simple models to more complex detailed simulation approaches, and then, based on this experience, to sophsiticated analytic (hence, simplified) models. I believe a change in direction toward more field operations analysis and interactive modeling will provide insights necessary to continue the trend.

SUMMARY

In summary, I have suggested a change in the direction of Army OR for the next decade -- a change that would provide more focus on operational studies to determine effective ways to employ the current and forthcoming generation of new Army systems. It should involve field measurement, experimentation, and simulation technology synergistically to analyze and create tactics and procedures for improved operations. I am not suggesting a complete reduction in systems analysis activities such as COEAs and long range force structure studies, but rather a shift to increasing emphasis of research on operations over the next 2 - 3 years in preparation for such work in the 1980s. I tried to indicate the nature of the proposed activities by delineating the types of issues that might be addressed. Clearly I have presented but a few of the issues in each of the subject areas mentioned and omitted other relevant operational areas for study such as engineering and medical operations.

I should note in passing that there are, of course, other study areas that, although non-operational *per se*, will warrant your efforts. They have benefits unto themselves and are mutually supportive with the research on operations. Some of these include the following.

- Development of management information systems as repositories for the large amounts of data that will accrue and the inventory of knowledge about military operations that will be created over the years.

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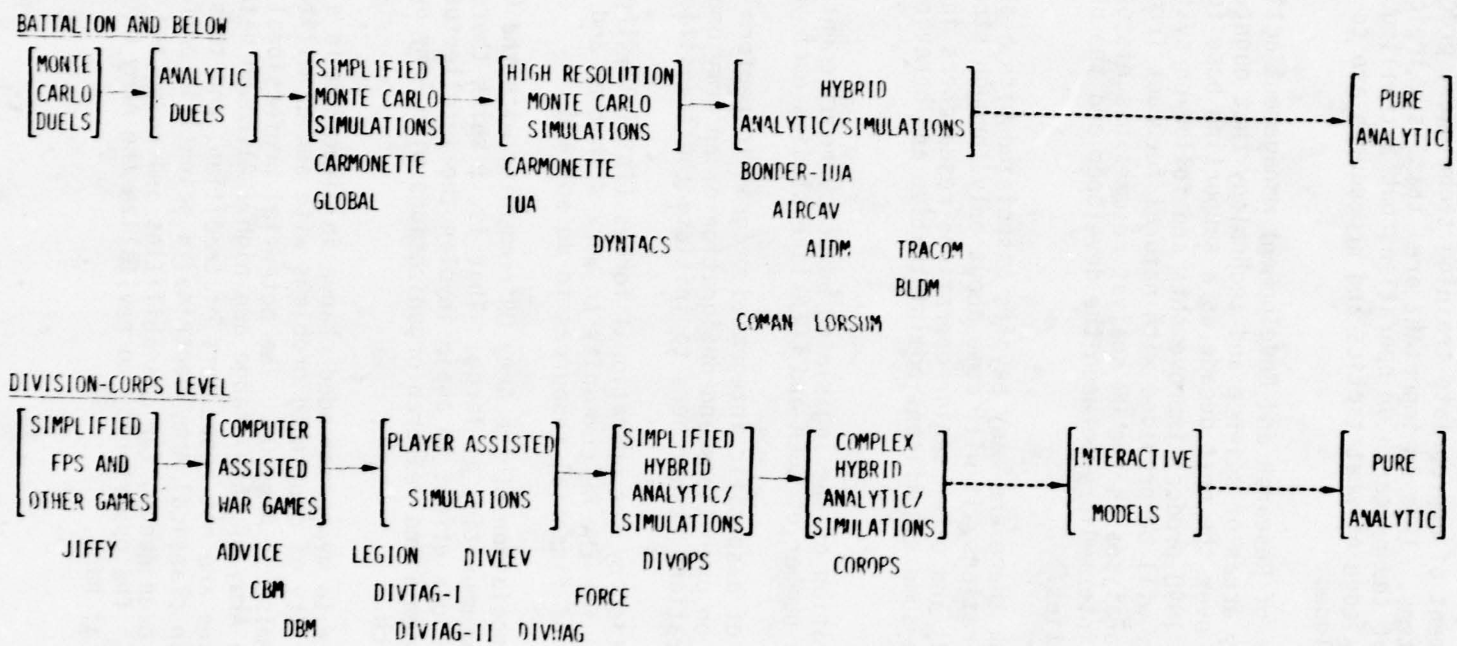
[1]Hunt and Starry, *op cit.*, p. 22.

[2]Which also has been identified in industrial OR model developments.

FIGURE 5: SUMMARY OF TRENDS IN COMBAT MODELING



- Development of appropriate training techniques, procedures, and systems. This an important area that is a logical companion of the research on operations but a trailing one until the knowledge of what tactics and procedures are to be taught is developed.

- Analysis of Research and Development management activities to identify areas of science and technology that ought to be pursued over the next decade as a supporting base for development of 1990 product improvements and follow-on systems. This activity will be provided with natural feedback from the operational analyses as the OR analyst resumes his historical role as the intermediary between the developer and the user communities.

Although I think there are many payoffs associated with a shift to more research on operations, it will come about only through strong guidance by the DUSA (OR) and other senior operations researchers in the Army. It will require some significant administrative and behavioral changes such as:

- A moderation of the legislated advocacy requirement to conduct a large number of COEA and COEA-like studies each year,

- Design of a specific integrated program to perform the research on operations and designation of an Army organization of operations researchers to initiate the transition activities,

- Invitation by the operational forces (initially those in Europe) for the OR community to work with them and the provision of financial resources to do so, and

- A reassociation of the Army OR community with the OR and scientific communities at large. That is, I think there should be a conscious effort to again involve the intellectual resources of academia and research organizations with Army operations research.

The alternative to my recommended change in direction is a not insignificant probability of continued problems with senior military managers and perhaps the demise of Army OR. The potential professional benefits and payoffs to the Army of this change are high. Although data-based scientific activities are not respectors of tradition, and thus may reveal some inadequacies in classical Army doctrine, a scientific profession has traditionally been needed for its abilities and respected for its contributions. The opportunity to revitalize the Army OR scientific profession is at hand.

REMARKS BY
GENERAL WALTER T. KERWIN, JR.
VICE CHIEF OF STAFF, UNITED STATES ARMY
TO ARMY OPERATIONS RESEARCH SYMPOSIUM (AORS XVI)
FORT LEE, VIRGINIA
THURSDAY, 13 OCTOBER 1977 (0900 Hours)

I am pleased to have the opportunity to address your symposium this morning. Your theme "Operations Research Support to the Army of the 80's -- Looking Ahead" is a challenging one. It led me to reflect on what I thought the Army of the 80's might be like. My perception of that Army is what I will speak about today.

To look ahead you have to look back. When I looked back over thirty-eight years of Active Duty, I saw an Army that had evolved from a small, mostly rifle oriented force. It is now dominated by anti-armor weapons. Crew served weapons are the order of the day.

The backbone of our Army has been, and will continue to be, its people. During these past four decades the Army's strength has varied depending upon whether we were involved in conflict. But the trend since World War II has been downward in manpower authorizations. This trend has reinforced the American desire to substitute firepower and materiel for people. We use weapons to make up for lesser manpower.

I see four challenges ahead to this approach. The first is the rising cost of manpower. The second is the need for more highly skilled soldiers to operate and maintain the new equipment. The third is the composition of the force -- that is, women in the Army. And the fourth is keeping our readiness up.

Manpower costs continue to rise. We want to keep 16 Active Divisions. But we may not be able to buy all the equipment we need as soon as we would like.

The need for increased skill levels for our equipment operators and maintenance personnel adds to the problem. It will cost more to recruit, train, and keep these skilled soldiers.

Inflation and advances in technology have pushed the costs of equipment up at the same time. All of this means that the Army is facing a serious "affordability crisis.." Hard choices between people and things will have to be made.

But I have faith in people. People will find ways to soften the impact of these hard choices. They will find quicker and better methods of training. People will find ways of organizing units to fight more effectively. People will also find ways to control the impact of rising hardware costs.

We are already experimenting. We are looking at division restructuring at Fort Hood. We will see if we can achieve more pay-off from our new weapons and equipment by organizing around our equipment. We may find that more efficient training will result

from organizing companies for specific weapons such as TOW. We have a plan to test this new concept extensively. I have no idea how these tests will come out. But I am convinced that the Army of the 80's must have the best organization possible. And that organization must get the most out of its people and weapons.

We are also looking at training and skill levels in another way. We intend to provide manuals which are keyed to the reading levels of our recruits. In this way our soldiers can read and understand the manuals more easily.

I also see the Army of the 80's as one which will have more equipment common to that of our NATO Allies. Rationalization, standardization and interoperability provide us the opportunity for a more effective Alliance defense. We can also realize economies in hardware production and in spare parts supply. Eventually we may share maintenance facilities with our Allies.

Now, as to force composition I see the Army of the 80's with more women soldiers than we now have. Women will be in more occupational specialities than at present.

During this year's REFORGER we tested the performance of women under prolonged conditions of simulated field combat. When the results are analyzed, we will know better the role of women in our units. We can begin now by treating all of our people as soldiers, not as men soldiers or women soldiers.

While people are the key -- they make everything work -- the world changes. We now have new challenges to our way of thinking about people. Changes in strategic realities pose new challenges to our way of thinking about the readiness of the Army. You Army analysts need to start helping us with ways to manage these new approaches.

We have traditionally defined the readiness of the Army in terms of unit readiness. We were able to measure the training, the personnel strength, and the maintenance status in a unit. We felt comfortable if unit readiness was high, at C-1 or C-2. But high unit readiness alone may not help us respond rapidly in the event of war.

Resources and production rates constitute one set of new realities. Shrinking reaction time and the nature of modern warfare constitute another. In the past, we have assumed that we would have enough time to react to a Warsaw Pact mobilization. We cannot now accept such an assumption. While we were engaged in Vietnam and shifting to a smaller All Volunteer Army, the Warsaw Pact increased and modernized their forces. We must begin to prepare the Army to react in as short a period as possible. We must have a significant capability to react within a week. The changed strategic situation means that a better way of looking at, and maintaining, the readiness of the Army is necessary.

We had to do more than just look at the unit readiness of a division, battalion, or company by itself. Unit readiness didn't tell us much about the responsiveness of the entire Army. Force readiness does. It includes unit readiness in the traditional way. But it also gives significant consideration to rapid mobilization, deployability and reinforcement, and sustainability. We are working out the details on how to measure and implement this concept.

But, let me explain a little more about how force readiness works. In the first place, the total requirements for force readiness are greater than for traditional unit readiness. For example, units from the United States which would respond to a European crisis would not be very effective until their equipment arrived. We therefore preposition equipment and reserve stocks in the NATO theater for them. In this example, the materiel requirements could double.

The constraints imposed by budgets and production rates mean that we can't do it as quickly as we would like. We may have to accept a lesser level of unit readiness in some elements of the Total Army here at home for a time. But we must improve the force readiness of the Army as a whole to be able to respond to a NATO crisis.

We will withdraw some equipment from the Army here in the United States to increase the combat power and the prepositioned and War Reserve stocks of the Army in Europe. The unit readiness of those elements at home, whether Active, National Guard, or Reserve will be affected. However, the equipment left behind by troops deploying rapidly to Europe would immediately become available for reallocation. Some of this equipment could be shipped by sea to forces arriving later. Some could be used to raise and train new forces for deployment in a lengthy war.

Force readiness does not mean battalions and divisions on continuous alert. It does include,

however, making sure that our soldiers have taken care of everything that would delay their deployment - shots and dog tags, for example, are some of the things that come to mind. The constraint on force readiness is not the physical availability of the soldier around the clock. Rather, the problem is to make sure that when units are required, they can deploy immediately.

Force readiness includes other means to improve the responsiveness and combat effectiveness of the whole Army. The Reserve Component Affiliation Program is an important element in our thinking about the force readiness of the Total Army. You are familiar with the Affiliation Program. Let me review its role in force readiness.

Affiliation is a method to bring our Reserve Component force to bear quickly in a crisis. Its success underscores the dependence of the Nation upon the National Guard and Reserves. Currently, 80 combat battalions from the Army National Guard and 16 from the Army Reserve are participating in this program.

My experience indicates that the Affiliation Program has been accepted with enthusiasm by both the Active units and the Guard and Reserve. Relationships have matured and mutual confidence has grown. The overall unit readiness of the affiliated units has also improved along with the force readiness of the Total Army.

On the other hand, force readiness is reduced by the decrease in the Individual Ready Reserve. We need people in the IRR to sustain the force in case of a prolonged crisis.

Rationalization, standardization and interoperability within NATO will also improve our force readiness. The President, the Secretary of Defense, and the Department of the Army are committed to this approach. RSI involves measures to improve the military effectiveness of the Alliance by more efficient use of Alliance resources. We can do this by making our equipment, supplies, and doctrine the same or compatible. If we can use the same logistics systems, then resources can be reallocated.

Our own force readiness can be improved. We will have greater flexibility as standardization in NATO increases.

We have hard work ahead to keep the quality of our people high and improve force readiness. We must do this despite the realities we face. We need new techniques of training management. We should have better approaches to preparation for overseas movement prior to a crisis. We must become serious about closer integration with our NATO Allies.

In closing, I am going to challenge you as analysts. The issues I have raised this morning reflect, in the main, operational concerns of field commanders. You Army analysts have, for a long time, focused primarily on the acquisition process for materiel. You must now look beyond force effectiveness based upon materiel performance. The Army of the 80's needs good analysis techniques to assist the field commander with his need to increase productivity, and particularly, force readiness. I challenge you to rise to the occasion.

Thank you.

SUBJECT: Science and Technology for the Army - A Systems Approach

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The Army has relied for a long time on its science and technology program to provide a technological edge over potential adversaries. The Army surely has the best tanks, helicopters, and anti-tank missiles in the world and this superiority will continue to hold in the future. There are capability areas, however, where we do not fare as well. For example, our potential enemies out-range us in artillery and have more capable air defense gun systems. To counter this we need to improve our technological capabilities so that we can achieve superiority across the board.

There is no need to settle for less.

Secretary of the Army Alexander and General Rogers, Chief of Staff of the Army, have established a list of goals towards which we must direct our efforts in order to sustain the United States' readiness to deter aggression and to support our allies in the commitment to preserve peace. The Research and Development community is charged to improve Army concepts and equipment through the exploitation of new technology. The thrust of this goal is one of constantly seeking to improve existing concepts and weapons systems while at the same time preparing for the evolutionary advancements and developments of the future. We are further directed to strive for the management goal of strengthening the Army's resource justification process while utilizing existing and programmed resources more effectively. The achievement of these goals is critical to maintaining the evolving offensive and defensive force capabilities on the modern battlefield into the 1990's and beyond.

In concentrating on these Army goals there are a number of significant steps which have been introduced into the overall management system applied to the scientific and technology program at the Department of the Army level. The primary staff agency for this is under the direction of the Deputy Chief of Staff for Research, Development, and Acquisition, Lieutenant General Howard H. Cooksey. (To be succeeded by LTG Donald R. Keith effective 1 November.) I will confine my remarks to the management of the initial phases of the development and acquisition process, which is to the steps involving research and exploratory development of new concepts and new weapons systems. This area deals specifically with the Army's Science and Technology Base and it is the portion of our total program for which I have the overall responsibility.

The objectives which we are striving for are as shown on this slide:

Slide: Objectives

- o Advanced Military Technology in High Payoff Areas
- o Improve Reliability, Availability, Maintainability and Durability of Army Materiel
- o Enhance Effectiveness of Army Personnel
- o Reduce Costs of Military Capabilities
- o Conserve Soldiers Lives in Combat Operations "Look to the Future"

I don't think it's necessary to explain to this audience that the R&D function is a highly dynamic and constantly changing one. I think most of us (and I hope I'm not dating myself to the point of extinction relative to some of the younger people in the audience) can remember the advent of radar, the Atom Bomb, jet aircraft, and the laser. I won't go all the way back to radio and talking movies. The revolution of technology is as familiar to us as the air we breathe. Only recently the Smithsonian added to its marvels a complete museum on air and space -- treating these wondrous things as historical artifacts almost before the ink is dry. The reason is obvious: If we stop to dally with any of these things the world will pass us by. New advancements are being examined today which were not even heard of when Chuck Yeager first flew faster than the speed of sound or even when Neil Armstrong first stepped foot on the Moon.

To meet General Roger's goals the Army must constantly strive to stay abreast of these advancements. And to do so requires a corresponding progress in our management techniques and systems. They must be innovative, coordinative, productive -- and futuristic. I believe we are taking positive steps in this direction.

Let me illustrate my perception of the problem in this slide and then outline my philosophy of management in the next one:

Slide: Managing to Achieve S&T Objectives

- o The Army in Battle: A Macro System
  - Communications, Command and Control, Mobility, Weapons Delivery and Effectiveness
  - A Totally Integrated Battlefield Matrix
  - Personnel Responsiveness: Care and Feeding, Medical, Housing, Combat Environment Constraints, Human Engineering

Slide: Philosophy of Management

- Establish Responsibility
- Provide Guidance: Funding/Requirements
- Review Output of Labs
- Determine Relevancy of Overall Program
- Make Adjustments

Put another way I am simply stating that we must seek always to be a part of the solution and not a part of the problem.

The following management mechanisms have been formulated and implemented in this coordination of the users' requirements with laboratory research and development efforts:

Slide: The Systems Management Tools

- o Block Funding
  - Single Project Funding
  - Single Program Element Funding
- o Army Science and Technology Objectives Guide (STOG)
- o Management Summary Sheets (MSS)
- o The Advanced Concepts Team

The first step needed was to provide greater responsibility and latitude to deal with the increased sophistication of research by delegating authority down to the labs. This was accomplished by block funding:

Slide: Block Funding (SPF/SPEF)

- o Lab Director has Authority - Responsibility
  - Decentralization of Control
- o Objectives Oriented - STOG
- o Flexibility to Adjust Funds/Programs
- o Latitude to Subcontract

Under the SPEF concept the laboratory director proposes a set of prioritized tasks and indicates what he expects to accomplish during the coming year. His approved program is then "block funded" and the director is held responsible for the performance of the laboratory. The laboratory director is free to change his program at any time in order to take advantage of technological opportunities which arise. There was a "carrot and a stick" mechanism introduced also, in that the budget for each laboratory is influenced by accomplishments in the previous year's program and the content of the proposed program.

Advanced planning for SPEF was well coordinated with the members of Congress and their staffs and they gave the Army their full support.

The move to delegate authority via SPEF, although a most important step, was only one of a number of changes that were made to improve the R&D process.

Clearly the lab directors were happy to get the authority that went with the SPEF. However, with the authority came the responsibility and the question, "What are the priority requirements my laboratory should address?" The answer to this question is provided by the Training and Doctrine Command (TRADOC) who speaks for the "user". Means had to be developed to bring the user and developer together early in the developmental process. We had to get the user to establish his needs in such a way that the laboratories could understand and respond.

The vehicle that was developed to identify user requirements was the Science and Technology Objectives Guide, or STOG. This was a completely new document which was implemented to establish a prioritized list of requirements and to replace five other earlier requirements documents. It's purpose is shown here:

Slide: Science and Technology Guide: Purpose

- To Provide Guidance to Army In-House Organizations, Private Industry and University Research Centers Regarding Army Objectives and Priorities
- To Assist R&D Managers in Evaluating S&T Relevance and Return-on-Investment

The STOG is broken out into Capability Categories as shown here:

Slide: Capability Categories (CAPCAT)

Each major Capability Category section is a listing, in priority order, of the user's needs within that category. For example, in the Capability Category Other Combat Support the highest priority need is "Rapid Emplaced Minefields" with specific characteristics such as variable time activation, remote deactivation and firing based on discrimination sensors. The next priority Science and Technology Objective (STO) addresses improved equipment/techniques for detection and neutralization of mine fields. And going further, the next one describes airdrop system requirements. An important point to note is that these STO's are clearly "user", rather than developer oriented. Each STO lists the user proponent who is most concerned with the objectives delineated as well as the laboratory that has been assigned the primary responsibility to see that the STO is adequately addressed.

Each Capability Category also contains a background section, a discussion of the general desired capabilities required (e.g., Rapid Enhancement of Mobility for Friendly Forces and a Counter Mobility Capability to Impede Enemy Forces), and a concept of operations.

The purpose of the concept of operations portion is to provide the laboratory director with the "big picture" of what is to be accomplished. He can then better understand the prioritization of the STO's which provides a basis for meaningful and innovative management as requirements change or as research opportunities become evident.

The dialogue between the scientist and the "user", once started, ran very smoothly. The first draft version of the STOG was prepared in the Office of the Director of Army Research but it was based on a dragnet of requirements that has been established in one form or another within the TRADOC community. It only needed a start.

The second iteration of the STOG, called STOG-78, was published in April 1977 and has been actively used since then. Laboratory directors have used it to redirect their programs to the Army's high priority needs, and management program reviews have used it as a basis to judge the responsiveness of the laboratory programs to the Army's needs. Last Spring Joint Laboratory Program Reviews were held and it is noteworthy that the TRADOC representative was a key figure at all reviews. He was able to compare the program against the stated needs that he represented. This had significant impact on program planning for the future. Further improvements and refinements for the STOG are being incorporated with the next edition as shown here:

Slide: STOG in the Future

- o Objectives: Timely, Update Annually
- o Oriented on Near Term as well as well as Future Requirements
- o Introduction of a Time Element
- o Increased Interface with Industry

A caution that must be kept in mind in any discussion of requirements documents related to a science and technology base program is that if we try to define the goals for the entire science and technology program we would be making a serious mistake. To do so would prove to be too constraining for a meaningful, productive program. We must leave room for innovation. The Army is sensitive to this concern. To quote from the Executive Summary of the STOG: "Nothing in this STOG is intended to depart from the essential SPF/SPEF management concept that R&D directors must determine where they can make the most significant science and technology contributions to the known or presently unforeseeable needs of the Army."

Approximately 70% of the 6.2 exploratory development programs should be in response to STOG objectives. The other 30% or so represents funds that are available for the laboratory director to use to pursue technological opportunities as they arise. Many new technological opportunities can be foreseen by the laboratories as the SPEF plans are being prepared, and can be included in the plan. When opportunities for innovation become apparent after the annual plan is published, the director still has the freedom to readjust the program. At the end of the year his lab is judged on the efficacy of the overall program. He does not have to adhere entirely to the plan he laid out at the beginning of the year but can make meaningful changes. He is of course expected to address the highest priority needs that his laboratory can satisfy wherever feasible.

To review the output of the labs we asked them to provide project information in the form of a "crosswalk." This did the following:

<u>Slide</u>: SPEF "Crosswalk"

- o Provides Bridge Between Lab Project Reports and Management Summary Sheets
- o Summarization of Effort by Objectives Capability Category

Given the STOG and given the laboratory programs, management now has the requisite information to evaluate the return on the science and technology investment. The Army compiled this information in Management Summary Sheets (MSS) modeled very closely after an approach utilized by the Exxon Research Laboratories.

The MSS are discussed here:

<u>Slide</u>: Management Summary Sheets (MSS)

- o Prepared for Major Thrusts in Each Subcategory
- o Backed by Data Sheets Enumerating Applicable Programs
- o Coordinates STOG, Spider Charts and SPF/SPEF X-Walks
- o Objectives Oriented

A sample MSS is shown on this slide:

<u>Slide</u>: MSS Sample

These sheets are intended to show in concise form:

1. What assumptions are required in the sub-capability category.

2. What the major thrusts of the program are.

3. What the STOG calls for within the sub-capability category.

4. What pacing problems the laboratories see.

5. The work being done to solve each pacing problem.

6. The laboratories doing the work, and

7. The dollar amount being spent on each problem area.

By preparing these MSS's by capability category rather than by laboratory organization the Army's total program in a given functional area is readily identifiable.

The full set which consists of 45 MSS's provides an excellent overview of that portion of the Army's science and technology program that is oriented towards solving problems stated in the STOG. It

turned out that (notwithstanding the guidance that a reasonable percentage of the program should be independent of STOG requirements) over 90% of the exploratory development program submitted was correlated with the STOG.

Careful study of the laboratory inputs showed few examples where the stated correlation with the STOG was unrealistic. This may well indicate that too much of the current 6.2 program is closely coupled to readily foreseeable application. This is a subject for further study.

Research Development and Acquisition Committee (RDAC)

The final step in the management process was the adjustment of funds based on the information presented in the MSS's. Balancing and readjusting R&D and procurement funds is normally carried out by a group known as the Research Development and Acquisition Committee (RDAC). This committee has representation from the R&D and operations communities, from TRADOC who represents the "user", as well as representation from the development organizations.

This year the RDAC added a special session that addressed the science and technology base exclusively. The MSS's provided the visibility and understanding of the program content that enabled the RDAC group to make funding adjustments within the 6.1 and 6.2 programs.

Another innovation which was introduced and which has proven very successful was the Advanced Concepts Team. The purpose of this action was to provide an immediate access for research items which showed great promise. A few points regarding the ACT are:

Slide: Advanced Concepts Team

- o Funds Innovative Concepts with High Near-Term Potential
- o Serves as POC for Inquiries from the R&D Community
- o Scientific Advisors with Long Experience
- o Over 500 Proposals Examined
- o 34 Programs Recommended for Funding

Summary: Success

I would like to summarize through the following slide:

Slide: Summary of Management Concept

Philosophy	Implementation
Establish Responsibility	Block Funding
Provide Guidance	STOG Sets Objectives
Review Output by Labs	SPEF X-Walk Catalogs Work
Determine Relevancy of Program	MSS Provides Overview
Make Adjustments	Tech Base Pre-RDAC

The Army has developed techniques which have provided improvements in the management of its science and technology programs, based on the premise that we put the authority and responsibility for laboratory programs with the laboratory director, where they belong.

If this authority is truly delegated to the director he cannot then be told how to run his programs. This does not mean that he cannot be helped with advice on what the Army's needs are.

This delegation of authority cannot be considered a blank check without the responsibility to provide the Army a return on its investment, either from an individual laboratory or from a number of laboratories working in concert. By compiling the major program thrusts in a more concise format, it is possible to determine which areas are not adequately covered and therefore where additional emphasis is needed.

The overall program is very complex, of course, and I have greatly oversimplified it here for discussion purposes. We also have a lot of rough edges to smooth out before we can say we have arrived. But we have noted some significant improvements throughout the system.

We hope to continue to look to the future -- to seek to identify problem areas and technological opportunities well in advance so that we can provide our ground combat forces with the finest weapons and equipment possible. It is a great challenge and an exciting work. And management is and will continue to be a critically important ingredient.

THE NEXT TEN YEARS IN ARMY OPERATIONS RESEARCH

by

Daniel F. McDonald,
Vice President, Technical Programs
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Walt Hollis asked me to speak with you tonight about the future of operations research in the Army. I have been at CDEC for six years helping the Army conduct experiments in the field. Recently I also spent some time with V Corps in Germany and this put me in contact with planners at Corps Headquarters and with battalion commanders and their staffs in their casernes. Walt suggested that these experiences had placed me in close contact with the Army, both experimenting and operating in the field, and this would give me a perspective from which to look forward to the next ten years of operations research.

First, let me congratulate those of you who are here this evening because you are participating in the development of a new science, operations research. Although it had its beginnings some 35 years ago and has made spectacular gains during that time, it is still new, still struggling. There are still some basic elements to be put in place before it takes its place beside the classical fields of science. But this is the aspect which is most stimulating, perhaps, to participate in the development of a new science and to look forward to the time when the systematic methods of operations research which you are helping develop will begin to have as profound an effect upon people's lives as have the classical sciences in the past.

In the case of us here tonight our position is especially advantageous because Army operations research has been leading the way during the last 35 years. We are also fortunate because at the senior levels of Army management the need for our services is clearly perceived, our activities are enthusiastically supported, and our solutions to problems are eagerly looked for. General Kerwin addressed us on this today. In his departing speech to TRADOC Commanders, General DePuy emphasized the central role that analysis plays in all of TRADOC activities. And now, succeeding General DePuy, we have General Donn Starry who sees OR as an essential part of the practice of the military profession, not only in TRADOC activities, but in the activities of the field commands. So we have, in those who are charting the course of the future of the Army, men who see a continuing, essential role for our activities in operations research.

The question before us is: How can we best respond to this situation? We can start by examining the current status of our activities and, in particular, the problems which confront us today, and find in those problems the opportunities to make real contributions, perhaps even breakthroughs, during the next ten years.

It is fair to say that much of the operations research--the modeling and analysis activities--has, during the last 15 years, been directed toward the materiel acquisition process. This was the area where there was a clear need and where quick gains could be made. The OR methodology, with the technology boost provided by the parallel advances in computer sciences, developed new and powerful ways to conduct weapon system effectiveness analyses. Remarkable gains have been made, but when we review the models that these OR efforts have produced, they appear to be developed almost exclusively for their roles in the acquisition process. But beyond that, they are of more limited use to planners in other areas and they are of no use to the field commanders overseas or to the commanders in the United States who are conducting exercises and training. Something seems amiss here! We have developed sophisticated methods to support the weapon systems selection process. Then we leave the commanders in the field with primitive, if any, analytic methods to help him employ these weapons effectively.

Let us examine some of the characteristics of today's combat models which prevent their use in a wider range of applications. It should be noted that these characteristics also cause difficulties even in their specialized roles of supporting weapon acquisitions.

Combat models are generally opaque--the users cannot observe the way in which variables interact within the models to represent on-going combat processes. As a result, almost everyone, including the model developer at times, has difficulty in using them. These models do not help in gaining insights into the dynamics of the combat processes which they represent. Users are looking for this help and when models do not provide it the users never develop real confidence in the models or their output.

Next, models typically require extensive data preparation to provide all the inputs and then, perhaps, extensive debugging before record runs are made. In many cases, these very activities of assembling the data to input the model and then debugging models are so informative in themselves regarding the problem at hand that running the model becomes almost unnecessary. In any case, the non-specialist does not have the time or resources needed for these activities.

The net effect of these two shortcomings is that, if anyone ever does, it is only the working-level analyst who really understands the model. Others are asked to take the results on "faith". Unfortunately, these "others" are often the higher-level decision-makers and military commanders whose weapon acquisition, force structuring, and weapon employment activities are being supported. These are often, indeed, men of little faith.

We may wish to regard these shortcomings as problems for the user rather than for the operations researcher. I propose that we must be much more user-oriented, and that a great deal of future strenuous effort must be directed toward making models user-oriented.

We should get on with these problems, and, in fact, there are prospects for real progress in the future. Already we are seeing breakthroughs in the development of techniques to expose the interiors of models and to allow direct examination of the on-going combat processes represented in them. TRASANA and the Combined Arms Combat Developments Activity at Fort Leavenworth have major programs in the development of interactive graphic techniques as key parts of their model improvement programs. These techniques are the light at the end of the tunnel and they offer the real possibility for building transparency into models.

If we look only at the techniques now being used, it may appear that the hardware facilities and the methods will limit this approach to only a few major installations and will not be broadly useful. This is a shortsighted view. Today's activities may, indeed, serve principally to demonstrate the great power of interactive graphics in accessing the interiors of models. Then many of you here will take up this lead, and, taking advantage of the rapid progress being made in computer hardware and software, develop the inexpensive methods needed to make interactive graphic techniques features available to all future users of models. This will take strenuous effort, but it represents a great opportunity lying ahead.

Next, I believe we can address also the problems of too much data preparation, too much debugging, and too much complexity which prevent today's models from being of direct use to many potential users, particularly tactical commanders and higher-level planners. It might be easy to say that these features of models are necessary if the combat processes are to be validly represented--to say that users must cope with these difficulties if they want our products. I recommend that we become strongly empathetic with the user and accept his seemingly conflicting requirements for simplicity and validity as a challenge to develop new classes of simplified models. Dave Hardison can tell you about a model he has developed for his HP Calculator, one for tank warfare which includes statistical terrain. Marion Bryson also talks about ways in which he can take the output data either of field experiments or of complex models and develop simple, time-stepped and rate-based analytical approaches to modeling combat processes. These are only some examples, and there are other and, perhaps, better ways for you to discover and develop simple and effective OR tools for our non-OR friends. These could be the media by which we bridge the communications gap which now prevents the OR analysts from working effectively with a much larger community of potential users.

The limitations of models which we have just discussed are really matters of methodology and technique and, as the discussion indicated, I think we can look for real progress in these areas in the next ten years. There is another and more fundamental limitation in models which confronts us and which is more than a matter of improving methodology or techniques. Our combat models do not simulate many important aspects of combat activities well! All of you have examples. A very common failing of combat models is that the combat processes in them occur at rates much greater than those of combat itself. For example, the rate at which losses occur on both sides in armor/anti-armor simulations are often much higher than are encountered in real combat situations. Another, and related, example

is the ratio of ammunition expended to targets killed in armor warfare. In models this number is derived from representation of target detection and selection, weapon system firing rate, P_ks, and other details of engagements. However this is done in models, the totals for ammunition expended per target kill are much less than those observed in actual combat. For example, recent experience in the Middle East indicates that it is realistic to expect to fire 40 rounds of APDS per threat tank kill. Yet, I believe this is a number which we don't typically reproduce in our models.

These difficulties are part of a general problem we have in what can be called the "bottom-up" development of a combat situation. By "bottom-up" I mean that the representation of combat is developed by representing combat activities at the lowest level of detail and developing the logical structure which assembles these details into a total combat process. This is a useful approach for many applications but it has often led to the kind of distortions of important aspects of combat which I have just mentioned.

The difficulty of simulating the combat process from the bottom up is not at all surprising. There are similar difficulties in simulating non-combat operations in the same way. Cost modeling is an example. When cost modelers have tried to develop a model of total weapon system production costs, for example, by starting at the lowest level of detail, the total costs predicted have been far below actual costs. In other words, we cannot account for the nail, the board, the hammer, the carpenter, etc., and then simulate the way these combine to yield total cost in a manner which is at all accurate. Yet there is a much greater opportunity to get data for these details and operations than there is for combat operations. Our problem in modeling combat processes is, therefore, not surprising.

There is then an enormous challenge, not only to the military operations research analyst, but to the operations research analyst in general. This is the challenge to develop the methods by which we can analyze operations at the lowest, simplest level of detail and then assemble these in simulations which represent the total operations involved.

How can we approach this problem? The path all the way to the final solution certainly is not clear, but I can make recommendations regarding the direction which I think our future efforts in combat simulation should take. First, the problem is not really a methodology problem. It is not likely to be solved by intensifying our efforts in the developments of methodologies and techniques along the lines we're pursuing today. Such approaches will solve the problems of model transparency and simplification, as we have said, but I do not believe they will get at the more fundamental problem of realism in simulating the total combat process.

I have already suggested that the operations researcher has limited his activity too much to supporting weapon system acquisitions and that he should broaden his constituency to include many others. Now I've suggested that we do not know enough about combat processes to simulate them well. A general recommendation, which addresses both problems, therefore,

is for us to get to know the Army and the way it operates much better than we do today. Two specific recommendations are: first, increase our interest in and attention to field testing--design, execution, and test results--and second, make a vigorous effort to develop ways in which we can help tactical commanders in planning their operational activities and in developing ways to train their troops the way they fight.

If you pursue these recommendations, you will move toward a much better understanding of Army operations in the field. I mentioned in the introduction that Walt Hollis suggested that my experience at CDEC and in V Corps would give me some perspective from which to view the next ten years in operations research. This is that perspective, that we must get to know the Army as it operates in the field, in all respects, much better than we do today if we are to develop the real understanding of combat activities we need.

The Army in the field in tactical operations, training, and field testing wants our support. CDEC experimentation has demonstrated how two-sided testing can give us an understanding of combat processes. MILES is coming down the pike and we can look forward to two-sided training. The Army needs our help to exploit these advances and develop ways to do realistic training and more, better, and less expensive field testing. And we can learn from it as we go those things we need to know to make better models.

You cannot do this at your desk, you cannot "wait for the report". You must visit the test operations to see how the data are collected and to understand how the Army operates in the field. I assure you that, if you spend more than a few days doing this, the experience will immediately provoke meaningful questions like: "Why is that platoon of tanks stopped?" and "Why didn't the Dragon team fire even once during the whole trial?" And if you get out and help the Army learn to train as it fights with MILES you will get similar insights into the operation of the Army in the field.

In summary, I can say that there is a future full of challenges and opportunities. I think we can best meet them by broadening our constituency within the Army, by becoming more user-oriented, and by spending at least as much time in learning how the Army operates as we do in trying to model those operations.

SUBJECT: Materiel Acquisition Affordability 12 OCT 1977

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I. Introduction.

Affordability is the determination of whether a requirement/proposal can be satisfied with available resources. The Army, with its growing materiel acquisition program of $7-10 billion per year is continually faced with evaluating the affordability of its broad scale modernization program.

Affordability exists when requirements exceed the available resources. The affordability problem can be addressed only by a systematic resource allocation/reallocation process. Within DOD's Planning, Programing and Budgeting System (PPBS), resource allocation is termed programing.

There are four types, or perhaps a better description is facets, of materiel acquisition affordability. Type "A" is total program affordability which is addressed each year during the development of the materiel acquisition program. The total Research, Development, Test and Evaluation (RDTE) requirement is to develop a modernized warfighting capability or provide new capabilities as rapidly as possible. During program development, the RDTE requirement is costed by fiscal year. The total procurement requirement is to buy these modernization/new capabilities, along with other items needed to sustain our Army as rapidly as possible. This requirement is defined in terms of both dollars and quantity by fiscal year. Resources, termed Total Obligational Authority (TOA), are also quantifiable. Office of Management and Budget (OMB) provides the Defense TOA to Office of the Secretary of Defense (OSD). OSD allocates TOA to each of the Services. Office of the Chief of Staff, US Army (OCSA) determines the amount of Army TOA to be allocated to the investment accounts (RDTE and procurement). Since the total requirement always exceeds the available resources (TOA), we have a continuing materiel acquisition affordability problem.

Type "B" - materiel acquisition "probable" program affordability. This type affordability consists of a series of "what if" analyses to determine the potential impact of probable future OSD/Congressional cuts to the TOA allocated for programing the RDTE and procurement appropriations. Analyses have been made to determine the answer to the question, "What would be the impact on the Army's materiel acquisition program if we received, in fiscal years w, x, y and z, a reduced level of funding?" Analyses have provided insight into what the program may look like after

it has been subjected to program and budget cuts. The analyst in this case must attempt to predict, based on historical data, a most likely budget TOA. The analyst then develops program adjustments based on terminations and delays in order to keep the annual costs within this likely budget TOA. These "what if" exercises have served as a sensitivity analysis to indicate what major and minor programs would be impacted.

Type "C" - ASARC affordability. There are, in fact, two types of ASARC affordability -- the normal ASARC affordability and an alternate ASARC affordability. Normal ASARC affordability assesses the impact of program tradeoffs for presentation to the decision maker. The tradeoffs are made from the investment accounts. Once requirements have been programed in the POM or FYDP, a new requirement/proposal can only be accommodated by making tradeoffs from within the current program. In this situation the tradeoffs are clearly defined for the decision maker. At most ASARCs the decision maker is presented with funding profiles for each of several acquisition alternatives. Some ASARC alternatives require a funding profile which exceeds that which is currently programed, requiring the identification of tradeoffs in order to remain within the TOA. Since the Deputy Chief of Staff for Research, Development and Acquisition (DCSRDA) is the staff officer charged with bringing the ASARC affordability problem to the decision maker, he is normally expected to define tradeoffs from his appropriations (RDTE and procurement). The affordability decision then becomes one of weighing the impact of the tradeoffs on the total program.

Type "C" Alternate - alternate ASARC affordability. It is possible to make tradeoffs from appropriations other than RDTE and procurement. To date, however, tradeoffs of this nature have not been accomplished. The Army, seeking to maintain a force structure of 24 divisions, has opted not to tradeoff manpower/force structure for a new weapon system. Due to the complexity of the Operations and Maintenance, Army (OMA) appropriation, a tradeoff, for example, closing Fort Swampy in order to fund a new weapon system has not been attempted.

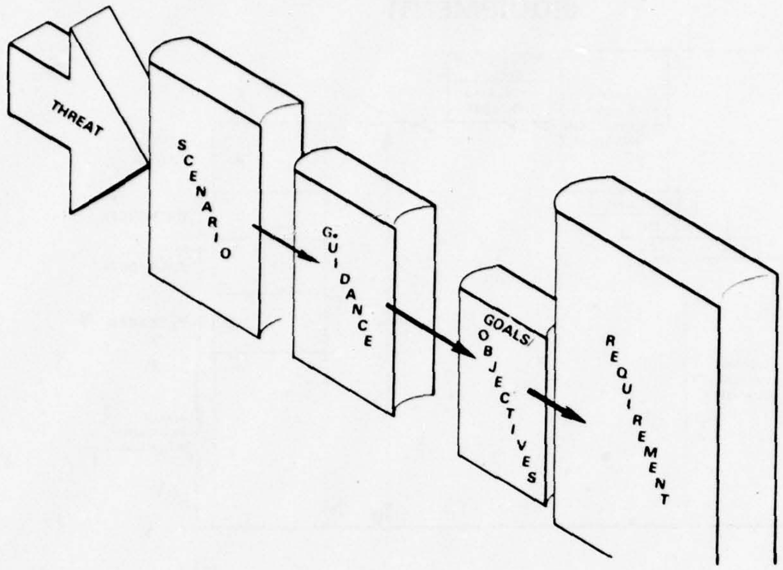
Type "D" - life cycle affordability. This type attempts to analyze the Army's ability to acquire, operate and support a new system over the life cycle of that system. This type of affordability is to be addressed by OCSA.

To attempt to adequately address any one of these four types/"facets" of materiel acquisition affordability requires a separate paper. This paper will therefore address Type "A" only.

II. The Requirement.

The total procurement requirement is based on a complex series of decisions as to how the Army will accomplish its mission.

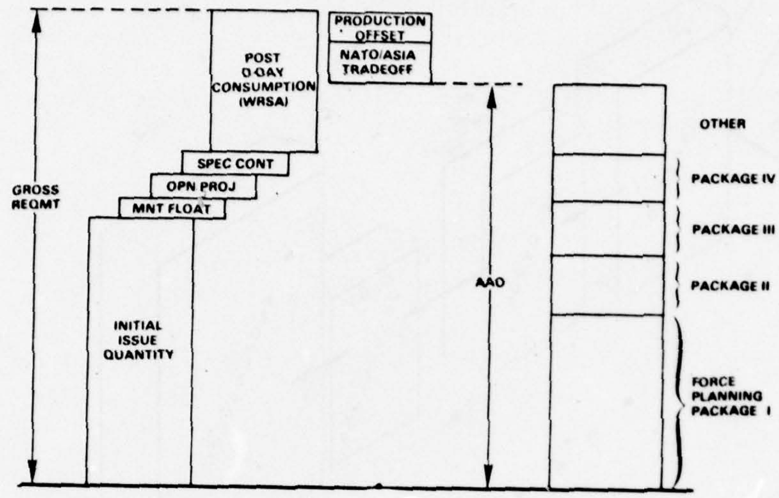
THE REQUIREMENT
BASIS FOR THE REQUIREMENT



For example, at the outset, the threat provides the basis for warfighting scenarios. These scenarios, when approved by OSD, govern the Allied and US force structures. Analysis of the warfighting capability of Allied forces within the scenario time period determines the planning guidance which drives programing guidance expressed in terms of POM goals/objectives. POM objectives serve as the basis for calculating the total requirement.

POM goals/objectives are two fold. General goals and objectives are those such as determining an appropriate balance between RDTE and procurement or between force modernization and other requirements (force shortages) in non-modernization items. Other POM goals and objectives are of a specific nature such as the sustainability objective. This objective defines the need to procure equipment and ammunition, for example, to support the D-Day force of XX divisions for XX days of sustained combat.

THE REQUIREMENT
ARMY ACQUISITION OBJECTIVE
(EQUIPMENT)



The procurement requirement is comprised of the initial issue quantity for each item in the force structure, the associated maintenance float requirement for that item, operational requirements and special contingency requirements for that item and finally the war reserve stockage. The requirement is defined as the Army Acquisition Objective (AAO). The many parameters of the AAO, which are continually updated, lend themselves to various stratifications which assist in program development

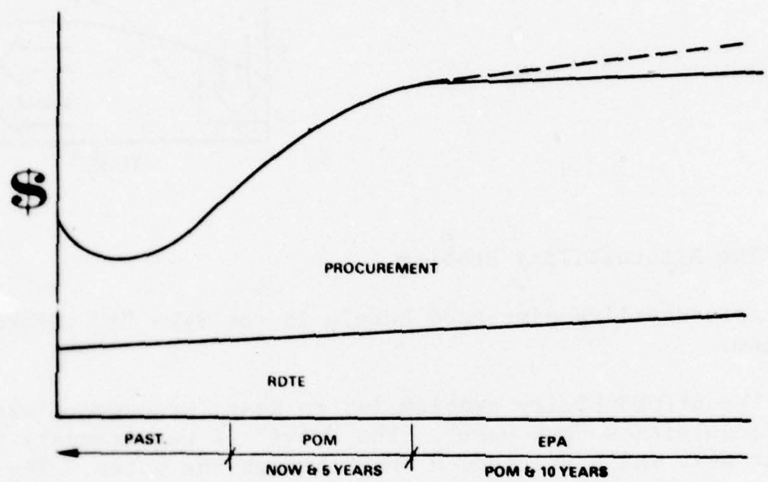
Each year growth occurs in the AAO. The growth is a function of numerous factors. For example, the Mideast war has shown us that our ammunition expenditure rate estimates were too low. The same analysis indicated that the War Time Replacement Factor (WARF) for hardware items needed to be increased. Force structure decisions, such as the conversion of infantry divisions to mechanized, cause growth in the AAO. Deployment schedules, which effect earlier deployment of divisions to the theater, cause an increase in the AAO. And lastly, as modernization items mature in R&D and enter production, significant increases in the AAO are effected.

III. Resources.

The classical definition of resources -- men, money, materiel and time is appropriate to the affordability problem. The principle constraint and the one which is the primary cause of the affordability problem is money. We are continually allocated less TOA than needed to satisfy the requirement. Resources, i.e., dollars by fiscal year, are

allocated during each PPBS cycle by OMB/OSD/OCSA. As previously stated, each year the Army allocates dollar resources to attempt to satisfy the total procurement requirement. This allocation, covering five years, is called the Five Year Defense Plan (FYDP). The May FYDP is called the Program Objective Memorandum (POM). Additionally, the Army projects dollar resources in the annual ten year extension to the POM called the Extended Planning Annex (EPA). In preparing the EPA, materiel systems are programed in detail for fifteen years. Other appropriations are programed in most instances as a "wedge"

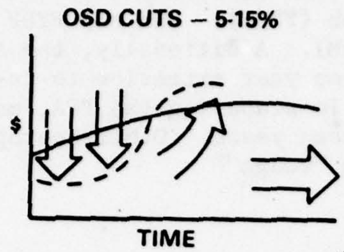
THE RESOURCES

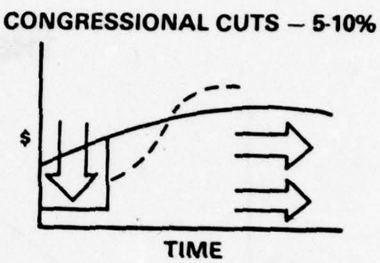


The dollar resources allocated to the Army each year are continually constrained. In peace time, DOD gets approximately one fourth of the federal budget. Currently the Army is allocated approximately one fourth of the DOD budget.

These projected dollar resources (TOA) are of questionable validity, however, as a programing tool. In light of a long history of continual OSD and Congressional cuts to the Army's RDTE and procurement programs each year, one is lead to question whether the current TOA is realistic. The outyear TOA currently programed will, in all likelihood, not be realized when the dollar resources are actually appropriated as a budget TOA.

THE RESOURCE CONSTRAINT
UNREALISTIC TOA'S



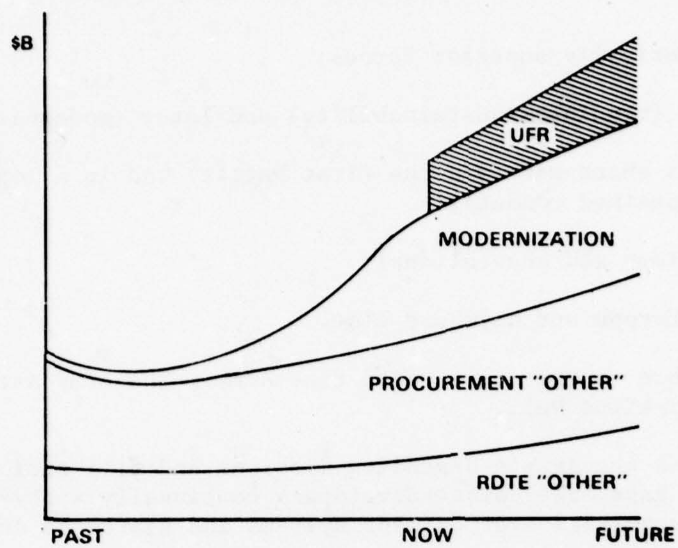


IV. The Affordability Problem.

Affordability discussed herein is the Type "A" affordability problem.

The affordability problem is, to most, synonymous with the materiel acquisition "bow wave". The "wave" of requirements is analogous to the wave which precedes a ship through the water. The "bow wave", a plot of Army modernization items over time, has been charted through the POM and into the EPA period. The modernization requirements build up dramatically in the coming years.

THE MATERIEL ACQUISITION "BOW WAVE"



Some perceive that the magnitude of the requirement, and therefore the "bow wave", is critical in some particular future year or period. The "bow wave" does in fact, peak in the early EPA period at approximately 50% of the currently programed procurement TOA. Over the past few years, this peak has varied from 48 to 53%. In perspective, this variance is not statistically significant. Discussions of when the "bow wave" peaks are academic, since we cannot afford our requirements now or in any future year.

There are solutions to the affordability problem; the most obvious of which is to obtain more TOA. This is, of course, easier said than done. The Army must convince the highest level decision makers that a sharp increase in Army procurement TOA is essential. The Army's materiel acquisition program attempts to equip a modernized fighting force as part of the NATO shield. As defense decision makers effect a change in the emphasis of defense strategy to focus on NATO, concomitant change in dollar resource allocation within OSD should occur. The Army's case to justify the reallocation of defense dollar resources must be solid, convincing and, preferably, analytically based.

A second course of action is to acquire less systems "more" optimally (realizing this is a redundancy in terms). In pursuing this course of action, the Army has attempted to kill, or more logically, not start major systems. This course of action is risky.

The Army's mission, in response to OSD guidance, demands that we be able to fight:

- Numerically superior forces;
- Now (readiness/sustainability) and later (modernization);
- In a short war (win the first battle) and in a long war (sustained combat);
- Nuclear and conventional;
- In Europe and anywhere else.

Yet we must be able to operate a peace time Army. The Army attempts to accomplish all missions well.

To accomplish the Army's demanding missions and fill serious battlefield capability gaps, the combat developers continually apply pressure to continue the acquisition of current systems and start the development of new systems.

The continued threat, lethality of the battlefield and the ability to close a battlefield capability gap with available technology extenuate any effort to kill or delay the start of a major system. It is therefore easy to make the decision to take "salami-slice" cuts to a large number of on-going, lower priority programs in order to afford a new system or the cost growth on an on-going system.

The final course of action is to acquire all systems "less" optimally. This has lead to attempts to develop a procurement "strategy". One "strategy" option is to stress and therefore place priority on the procurement of readiness/sustainability items. A second "strategy" option is to place priority on the procurement of modernization items. The final option is to develop a procurement program which balances modernization with readiness and sustainability. Army force planners are faced with numerous, inter-related planning uncertainties, such as those described above. In attempting to minimize all risks, the planner presents the programer with numerous additional programing constraints. This minimization of the planning risk forces the selection of the strategy option which develops a balanced procurement program.

The terms "more" and "less" optimally bring up the question of just what is the optimum procurement program, given the TOA constraint, the constraint that we must continue all acquisitions and the numerous constraints placed on us by the force planner. In ORSA terms, what is the objective function? What is it that we are trying to maximize with our procurement program? Is it force effectiveness? If so, how do we tie force effectiveness to our procurement program? What are the measures of force effectiveness?

Given the numerous constraints described above, how can the Army develop an optimum procurement program? As mentioned at the outset of this paper, the affordability problem can only be addressed by resource allocation, i.e., programing. Programing (resource allocation) models for materiel acquisition exist albeit in various stages of development. The Vector Research model, for example, a proposed mathematical model to optimize the Army's procurement program, has been submitted to the Army. ADRA II (Army Dollar Resource Allocation), being developed by the Concepts Analysis Agency, is to provide a methodology for determining the impact of potential programing actions. ADRA II, which addresses all Army appropriations, is scheduled to be completed in March 1978. These models are being evaluated for potential use in materiel acquisition programing.

Resource allocation, a principal management function, requires the skillful use of the best available management tools. Resource allocation tools are used to assist in the development of the materiel acquisition program. The Army has developed a materiel acquisition program structure called capability categories (CAPCATs). Every RDTE project and procurement item is coded in a data base. The CAPCAT structure is used at the Research, Development and Acquisition Committee (RDAC) meetings to develop an integrated, balanced materiel acquisition program. The structure is used by TRADOC to assist in determining relative priorities and by DARCOM Battlefield Integration Systems (BSI) Office for program analysis. Finally, CAPCATs are used to brief the Army materiel acquisition program in order to "sell" our basic case and to justify the need for additional TOA.

The Army has established materiel acquisition program priorities. Every RDTE project and procurement item is coded with a DCSOPS and TRADOC priority. Additionally, procurement items are coded with a force planning level priority established by OCSA. These priorities are displayed on programing documentation and assist in materiel acquisition decision making.

Numerous programing aids have evolved, the most recent of which is computer graphics. The RDTE and procurement data bases are on-line during all RDAC meetings. Graphic displays which indicate the results of multiple program decisions, aid the materiel acquisition decision maker.

Unfortunately, strong biases exist. Decision makers at all levels from the program manager's office on up to Congress have biases which are in most cases not analytically based but which have enormous influence on materiel acquisition programing decisions.

V. Summary.

The affordability problem is complex. This paper has described four types or facets of materiel acquisition affordability and addressed one type. The Type "A" problem is real and faces us now.

There are solutions to the Type "A" affordability problem. The problem is, however, enormously constrained. In the face of these numerous, complex, interactive and frequently unquantifiable constraints, the programer's challenge is to attempt to optimize the Army's materiel acquisition program.

A TIME STEP MODEL FOR REPLAYING SIMULATED BATTLES

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ABSTRACT. In field experiments, such as are conducted at CDEC, and in large computer simulations the outcome of the simulated battle is recorded by evaluating each of several measures. Examples of such measures are: friendly casualties, enemy casualties, targets detected, and integrity of attacker formations. This paper discusses a procedure for dividing the battle into a sequence of short battle segments. Measures of each segment are assessed. A simple model is used to aggregate the measures over the entire battle. The outcome of this aggregated battle is a much improved estimate of the mean battle result.

1. INTRODUCTION. In the generation of data in simulated battles, there are often too few replications of any given situation to assure stability of the results. This paper suggests a method of using the results of all trials to stabilize the estimates of some of the key measures of effectiveness. A realistic example of a field experiment is used as the vehicle for presenting the details of the method. Although the field experiment will be used for the discussion, the method is equally applicable to war games, both manual and computer assisted, and to stochastic computer models.

2. TEMAWS: A FIELD EXPERIMENT. During the Fall of 1976, USACDEC conducted a field experiment entitled Tactical Effectiveness of Minefields in the Antiarmor Weapons System (TEMAWS). A detailed discussion of the experiment is contained in the reference report. The TEMAWS experiment consisted of simulated battles waged between two forces; the blue force on defense using antiarmor weapons including scatterable mines, and the red force on the attack consisting of attacking tanks with antiarmor weapons in support. These battles were played by typical soldiers operating the actual systems in typical terrain at Fort Hunter Liggett, California. Using accepted tactics, the players engaged in armor combat, performing all typical combat functions of maneuver, target acquisition, firing, command and control, etc. The only planned differences between a TEMAWS trial and actual combat were

A. M-60 tanks were used to simulate T-62 tanks.

B. M113 APC's were used to simulate Soviet antitank weapons.

C. When a firing took place, a launch simulation cue was produced along with an eye safe laser beam instead of a projectile or missile.

D. Casualties were assessed in real time by a computer using accepted probabilities of kill for the given engagement situation.

E. The mines did not detonate. When encountered, they sent a message to the computer.

In the portion of TEMAWS analyzed by the time step model the only two controlled variables used were:

A. 7 minefield densities (0 to .01 mine/square meter).

B. 3 mine detectibilities (about .9 to about .3).

In each trial of TEMAWS there were five defensive weapons in addition to a scatterable minefield. They were two TOW weapons placed 2000 to 3000 meters from the minefield, two DRAGON weapons placed 500 to 1000 meters from the minefield and one M-60 tank placed about 1500 meters from the minefield. The red force on the attack consisted of from 12 to 15 T-62 tanks, two BMP's, one BRDM with SAGGER and indirect fire support. During a trial the threat antitank weapons assumed overwatch positions on high ground. Their function was to detect and engage the blue antiarmor weapons. The red tank force then attacked along a designated route. By design, the attack route went through the preemplaced scatterable minefield, so positioned the red force could not by-pass it. As the first tank entered the minefield, the defense weapons were ordered to open fire. The battle continued until one of the forces was annihilated or until the last red tank exited the minefield. In six trials, there were no defensive weapons employed. The purpose of these trials was to determine the effectiveness of a minefield not covered by fire. In eight other trials there was no minefield.

Each time a firing took place, a laser beam was emitted by the firing weapon. The targets, equipped with laser sensitive receivers, sensed the impinging laser energy if the firing weapon was accurately aimed. The computer acting as a master controller went through the following steps: A. Received a firing message from the firer, B. Received a hit message from the target. C. From telemetry computed the relative location of both firer and target. D. Calculated a probability of kill for that firer against that target at that range. E. By a random number draw made a determination of the outcome of the engagement. F. If the target was assessed as a casualty, (1) the target was so notified and (2) the weapon of the target was disabled by the computer. The crew of the target weapon system released a smoke cue to inform other players of their casualty status.

When a red tank encountered a mine the mine sent a signal to the computer which then determined by a random number draw whether the tank was a casualty. If it was so assessed, the above procedure for indicating a casualty was followed.

3. DATA BASE. The data from the trials which were analyzed for this report are indicated in Table 1.

TABLE 1

NUMBER OF TEMAWS TRIALS ANALYZED

Mine Detectibility	Minefield density (Mines/M^2) None	.00025	.0005	.001	.003	.005	.01
High (.9)		3	5	5	3+3*	6	
Low (.6)	8		4	6	6+3*	5	4
Very low (.3)				3			

*In three trials in each of the .003 cells there were no defensive weapons employed.

There were many measures of effectiveness evaluated in TEMAWS. Among these were

A. Red casualties.

B. Blue casualties.

C. Exchange ratio.

D. Movement rate of red tanks.

E. Probability of mine avoidance.

Additionally, casualties can be measured in two ways: the actual casualties assessed by the random number draw and the expected casualties computed from the calculated P_k values. In the latter method, for each engagement the firer is credited with a number of kills (always less than one) equal to the kill probability calculated for that engagement. The two methods have the same expected value, however, the latter method has a smaller variance. For that reason the total kills are calculated from the "sum of P_k" method. This paper will use red tank casualties as the only measure for analysis. For the discussion to follow we will use the following definitions.

A. Cell-a group of trials in which the mine detectibility and density are the same.

B. Trial-one complete simulated battle.

C. Trial unit-a small fraction of a total trial.

D. Column-similarly designated trial units, e.g., the first fifth of each trial.

4. TIME STEP MODEL LOGIC. As can be seen from the above table, there are few trials in any one cell. For trials in which all controlled variables are the same there are many uncontrolled variables which cause the outcome of the trials to differ. Among these uncontrolled variables are environmental conditions, mechanical failures, instrumentation malfunctions, personnel behavior, etc. There are other controlled or measurable conditions which affect the trial results. Among these are trial site and crews manning the systems. With all of these factors interacting to cause trial results to differ, the measure of effectiveness evaluated for the three to eight trials in any given cell will differ considerably. With this large intracell variation, any effects on the measure of effectiveness caused by the variables of interest are often indistinguishable. For example, we may like to know what is the effect of minefield density (a variable of interest) on the casualty exchange ratio (a measure of effectiveness). If the casualty exchange ratios in the trials in a given cell are highly variable, any effect minefield density has on this ratio would have to be great for it to be distinguishable.

Two ways to improve this situation are to reduce the intracell variance and to increase the sample size. Given that as much as possible has been done about the former, we must find ways to effectively increase the sample size.

First, let us choose a measure of effectiveness which:

A. Is meaningful.

B. Is measurable.

C. Changes as the simulated battle progresses.

D. Is sensitive to the variables of interest.

E. Is quantitative.

The more basic this measure of effectiveness, the better it will be.

A basic philosophy of the time step model is that over a short period of time, because only a few events take place, the battle situation can be considered constant. Instead

of analyzing the outcome of an entire trial, analyze the outcome of each of several trial time segments, which we have called "trial units," and connect the results of these analyses into a trial outcome. For example, if there are four trials in a cell, analyze the results of the first (say) one-fifth of each trial to obtain the mean trial unit outcome. The number of trial units in each trial is arbitrary. This number should be the same for all trials and should be chosen such that it is long enough for several engagements to occur and short enough that the tide of battle does not change significantly. The theory is that there will be much less variation in the outcome of small trial units than in total trials. After analysis of the results of the first trial unit, analyze the results of the second trial unit in each trial of the cell and determine the outcome of the second trial unit, using the mean outcome of the first trial unit as the starting point of the second trial unit. Continue this process until all trial units have been analyzed.

If the measure of effectiveness has been properly chosen, the mean value of the measure for each of the five trial units over all trials in all cells can be used to determine the trial unit to trial unit change in the measure. Similarly, the mean of all trial units in all trials in a cell will produce a value which can be compared with such means from other cells. Using the overall trial unit means and the overall cell means of the measures as weighting factors, a low variance estimate of the measure for each trial unit in each cell can be calculated.

5. EXAMPLE OF DATA GENERATION. From the TEMAWS experiment, the overall measure of effectiveness chosen was "red tank casualties." This measure was decomposed into two basic measures: probability a given live red tank is killed by any mine during a trial unit and probability a given live red tank is killed by a given active blue weapon during a trial unit.

First, each of the 64 trials was divided into 5 equal time segments, forming the trial units. The first trial unit began when the first red tank entered the minefield and the fifth trial unit ended when the last tank exited the minefield. The length (in time) of the trial units varied from trial to trial.

All engagements of defensive weapons firing at red tanks in each trial unit were listed. The probabilities of kill for engagements by DRAGONS, TOWS, and the blue tank were listed separately. The number and identity of all blue weapons which were active was recorded for each trial unit. A blue weapon was defined as active if it

A. fired in that or any subsequent trial unit <u>or</u>

B. was fired at in that or any subsequent trial unit <u>and</u>

C. had not been killed.

Finally, the number of red tanks which were alive at the beginning of the trial unit was recorded. The summary for one of the trials is given in Table 2.

TABLE 2

TRIAL DATA SUMMARY

MEASURE	TRIAL UNIT I	II	III	IV	V
Total DRAGON Kills	.57	.43	0	.39	0
Total Tank Kills	.14	.29	.41	0	1.43
Total TOW Kills	1.44	.75	0	1.49	1.13
Active DRAGONS	2	2	1	1	1
Active Tanks	1	1	1	1	1
Active TOWS	2	1	1	1	1
Red Tanks Alive	13	11	9	8	7

For the remainder of the example, the calculations for the TOW only will be exhibited. Those for the blue tank and the DRAGON proceed similarly.

The next step is to compute in each trial unit of each trial the number of active firer-target pairs. This calculation is simply the product of the number of active TOW multiplied by the number of live red tanks. In the example of Table 2 the number of firer-target pairs for the five trial units are 26, 11, 9, 8 and 7.

Now compute the number of red tanks killed by all TOW in all 64 trials for each trial unit. Also compute the total number of firer target pairs and thence by division the probability a given TOW will kill a given tank. Table 3 shows the TEMAWS summary.

TABLE 3

TOW KILL SUMMARY BY TRIAL UNIT

TOTAL	TRIAL UNIT I	II	III	IV	V
Red tanks killed in all trials	25.23	33.52	38.86	36.71	36.04
Firer-target pairs	1286	1076	828	603	398
Prob a given TOW kills a given tank	.020	.031	.047	.061	.091

Perform a similar computation for all trial units in each cell, that is, compute total kills, firer-target pairs, and P_k over all trial units and all trials in a cell. Table 4 shows the data.

TABLE 4

TOW KILL SUMMARY BY CELL

CELL DESIGNATION Mine Density	Detectibility	MEASURE Total Kills	Firer-tgt Pairs	Pk
0		30.81	887	.035
00025	high	11.59	207	.056
0005	high	11.86	288	.041
	low	4.99	260	.019
001	high	15.07	343	.044
	low	21.91	476	.046
	very low	10.16	207	.041
003	high	13.34	217	.062
	low	18.04	452	.040
005	high	20.74	488	.043
	low	4.65	139	.034
01	low	7.18	186	.039

It is now recognized that we have marginal estimates for the P_k, the column estimates being for the five trial units, the row estimates being for the 12 treatment combinations (cells).

The assumption is now made that the individual P_k which should be assigned to a given trial unit in a given cell should be the cell P_k weighted by the relative overall trial unit P_k. The trial unit weights to be applied should have a mean of unity and have the same relative values as the column P_k. These weights in the example are 0.40, 0.62, 0.94, 1.22, and 1.82. Finally, using these weights as multipliers the final values of P_k for each trial unit for the TOW are calculated.

Similarly the weighted P_k for the other two weapons are calculated. The final P_k values for all weapons for "001 low" cell are shown in Table 5.

TABLE 5

WEIGHTED P_k VALUES FOR
DEFENSIVE WEAPONS FOR CELL .001 LOW

	TRIAL UNIT				
WEAPON	I	II	III	IV	V
TOW	.018	.029	.043	.056	.084
DRAGON	.004	.008	.010	.009	.016
TANK	.014	.013	.033	.037	.048
MINE ENCOUNTER (see below)	.059	.065	.073	.059	.055

Using a similar, but simpler, method the weighted probability that a tank encounters a mine in each trial unit of each cell is computed. The column overall probability of encountering a mine is simply the total number of tanks which entered that trial unit in all trials divided into the total number of mine encounters in that trial unit. Table 6 shows the TEMAWS result.

TABLE 6

MINE ENCOUNTERS

	TRIAL UNIT				
DATA ITEM	I	II	III	IV	V
Total tanks entering trial unit in all trials	869	771	631	484	402
Total mine encounters	74	71	67	41	32
Prob a given tank encounters a mine	.084	.094	.106	.085	.080
Normalized value (mean value=1)	0.93	1.05	1.18	095	0.89

The cell values are shown in Table 7.

TABLE 7

MINE ENCOUNTERS
BY TREATMENT COMBINATION

TREATMENT COMBINATION		DATA ITEM		
DENSITY	DETECTIBILITY	Tank-Trial Unit Pairs	Total Mine encounters	Probability of Encounter
00025	high	139	2	.014
0005	high	260	9	.035
	low	185	9	.049
001	high	549	23	.041
	low	582	36	.062
	very low	125	19	.152
003	high	281	16	.057
	low	404	64	.158
005	high	280	20	.071
	low	247	35	.142
01	low	114	50	.439

Multiplying the normalized trial unit values from Table 6 by each of the encounter probabilities in the last column of Table 7 produces a matrix of probabilities of mine encounters per red tank for each trial unit in each cell. This table is not reproduced here, however the last row in Table 5 is a sample row from that matrix.

The objective of the time step model is to hold all factors constant except those which are affected by the variables of interest (minefield configuration in this case). It is believed that minefield configuration affects the kill rate of the defense weapons and the mine encounter rate. For this reason those variables are evaluated separately for each cell. Also, the weapon kill rate and the mine encounter rate vary over time into the battle. For that reason, separate values have been calculated for each trial unit. With those values varying from trial unit to trial unit and from cell to cell, all other inputs will be held constant and the battle replayed for each cell.

The major factors which will be constant from cell to cell are: number of red tanks entering trial unit 1 and number of blue weapons active at the beginning of each trial unit. These latter values are the mean number of TOW, DRAGON, and tanks active in each trial unit the mean taken over all TEMAWS trials. Table 8 shows these values.

TABLE 8

MEAN NUMBER OF ACTIVE DEFENSIVE WEAPONS

	TRIAL UNIT				
WEAPON	I	II	III	IV	V
DRAGON	1.4	1.3	1.1	0.8	0.5
Tank	1.0	0.9	0.8	0.7	0.6
TOW	1.7	1.6	1.5	1.4	1.1

6. OPERATING THE MODEL. We now assume that at the beginning of a trial there are 15 red tanks alive. These tanks enter the battle and may be killed, in the first trial unit, by one of the defensive weapons or by a mine. The number of defensive weapons, the number of red tanks, and the probability that a given defensive weapon kills a given red tank are all now part of the data base. Since the probability of kill of a mine given an encounter is classified, we will assume a fictitious P_k of 0.5 given an encounter.

The model now calculates the red casualties from each of the four casualty producing sources. The number of red casualties from a defensive weapon type, say TOW, is (number of TOW active) x (number of red tanks alive) x (probability a given TOW kills a given red tank). From the data given in Tables 8 and 5 and from the given 15 entering tanks we calculate for the "001 low" cell the following red casualties:

by TOW 1.7 x 15 x .018 = .46

by tank 1.0 x 15 x .014 = .21

by DRAGON 1.4 x 15 x .004 = .08

From the mines we expect casualties equal to (the number of red tanks alive) x (the probability a tank encounters a mine) x (the probability of kill given an encounter). In our example the following are expected tank kills by mines.

15 x .059 x .5 = .44

The total red casualties in trial unit 1 then are 1.19. By subtraction, we see that 13.81 tanks are still alive to enter trial unit 2. Repeating the above process, using trial unit 2 values from Tables 5 and 8 and 13.81 live red tanks we get the following casualties during trial unit 2:

From TOW	.64
From tank	.16
From DRAGON	.14
From mines	.45
	1.39

By subtraction we see that 12.42 tanks enter trial unit 3.

This process is continued through trial unit 5. The final number of surviving red tanks (or alternately the total red tank casualties) is the measure of effectiveness of that minefield. The final values for the example are as shown below.

Casualties in trial unit	3 = 1.72
	4 = 1.52
	5 = 1.43
Total casualties	= 7.25

The model is exercised similarly for each treatment combination. The outcome of this exercise for all cells produced casualty totals, the lowest being 6.30 for the case with no mines and the highest 13.42 (near annihilation) for a .01 low detectibility minefield.

7. SUMMARY. The time step model described and illustrated above has the following characteristics:

A. It is a pencil and paper model which can be exercised very quickly to indicate general trends in experimental results.

B. It adjusts cell means by use of overall means. A basic assumption in this feature is that there is no interaction between the time units and the cells in the design. That is, if the probability of kill for a TOW against a tank doubles between trial unit 1 and trial unit 2 in one cell, it doubles in all cells.

C. Other controllable or observable variables can be considered in the model. For example, the site on which the trial occurred or the crews which manned (or personned) the weapons may cause results to differ. In a side analysis of TEMAWS data the effect of the sites on which the trials were run was assessed. Site had trivial effect on the tank and TOW effectiveness but had a significant effect on DRAGON effectiveness. On site 2 the DRAGONS on the average were more than twice as effective as they were on site 1. A site adjustment was made in the DRAGON P_k values for each cell depending upon which sites were represented in the cell. The crew effect on the measures of effectiveness was minimal.

D. The number of trial units can be chosen to fit the situation. The trial units can be of constant lengths from cell to cell but, then, the number of trial units in a trial would vary. It is felt that a constant number of trial units is preferable.

8. REFERENCE. Tactical Effectiveness of Minefields in the Antiarmor Weapons System (TEMAWS), Final Report, Volume 1. USA Combat Developments Experimentation Command, Fort Ord, CA, June, 1977.

REPORT ON OUR CONTRACTUAL REVIEW OF THE QUALITATIVE AND QUANTITATIVE VALUE OF TACTICAL MOBILITY

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As I turned over in my mind several days ago just what facet of our tactical mobility study would be of most interest to this audience, my first reaction was that this must surely be the methodology because this is an operations research symposium. However, as I studied again the exact words of the title that had been assigned to me, I thought you would probably be as interested in the results as in the methodology. And that is just as well since I would not have time to discuss either the methodology or the analysis in any great detail. I shall therefore try to summarize both in the time available and if anyone is interested in further details he will have to refer to the final report which is scheduled to be delivered to Mr. Hardison's office early next month.

The purpose and scope of our study is shown on this slide.

PURPOSE

- DETERMINE WHAT HAS BEEN LEARNED ABOUT THE VALUE OF TACTICAL MOBILITY AND WHAT IT MEANS
- DELINEATE THOSE INVESTIGATIONS STILL NEEDED TO MEASURE THIS VALUE

SCOPE

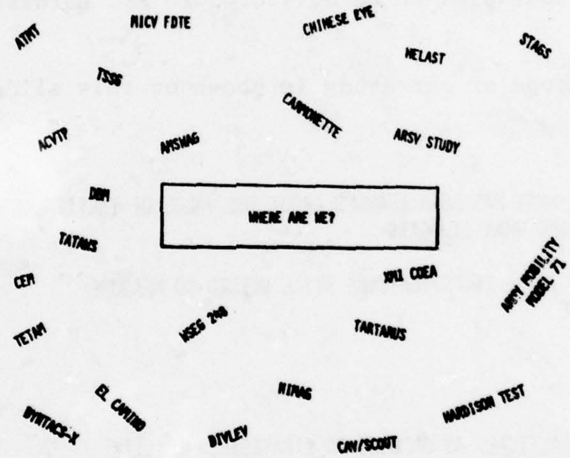
- FOCUS ON TACTICAL, AS OPPOSED TO STRATEGIC, MOBILITY
- CONCENTRATE ON GROUND COMBAT ELEMENTS IN THE THEATER OF OPERATIONS
- CONSIDER MOBILITY TECHNOLOGY ONLY AS IT CONSTRAINS MOBILITY ACHIEVABLE 1977-2000

The general approach was outlined in our statement of work and included these items.

GENERAL APPROACH

- CONDUCT A LITERATURE SEARCH
- CONVENE A TACTICAL MOBILITY WORKING MEETING
- CONSTRUCT A ROUTE MAP (TAXONOMY) OF THE ENTIRE AREA (EXPLORED AND UNEXPLORED)
- ANALYZE AND SYNTHESIZE INFORMATION AS BASIS FOR FINDINGS AND RECOMMENDATIONS

The first step is obvious since we were to perform what is essentially a review of the state of the art with respect to determining the value of tactical mobility. The second involved convening, under the sponsorship and direction of the study sponsor, DUSA(OR), a working meeting of the leading experts in tactical mobility and related areas. This meeting was held July 26-28 at the National War College in Washington. This proved to be of inestimable value to the study, not only because it brought to our attention information from recent and ongoing studies which had not yet come into the literature, but also because it provided invaluable insights by knowledgeable people currently wrestling with problems in this area. The third step was the most challenging to the analyst because it could be likened to making a sketch or route map of a major continent of which only small portions had been thoroughly explored. Clearly such a route map or taxonomy should be a guide to assist in further exploration. The last step could, of course, be accomplished only after the taxonomy had been constructed. Our feelings, after a very preliminary search of the literature are probably best expressed by this slide.



I shall spend the next few minutes telling you how we went about answering this question and developing a method for mapping the unexplored as well as the explored territory.

PROBLEM:

STRUCTURE A FRAMEWORK THAT WILL PORTRAY RELATIONSHIP OF MOVEMENT CHARACTERISTICS OF GROUND COMBAT VEHICLES TO GROUND COMBAT MISSIONS.

OBJECTIVES:

- ESTABLISH A TAXONOMY FOR CLASSIFYING EXISTING LITERATURE
- DEVELOP SCOPE OF RELATIONSHIP
- ESTABLISH LINKAGES BETWEEN MOVEMENT CHARACTERISTICS AND MISSION ACCOMPLISHMENT
- ESTABLISH A BASIS FOR TRADE OFFS
- ESTABLISH A BASIS FOR ASSESSING:
  - WHAT IS KNOWN
  - WHERE ARE GAPS
  - PRIORITY FOR FILLING GAPS
  - WHAT SHOULD BE DONE

The problem and the objectives we set for ourselves are shown on this slide. Our approach to meeting these objectives is shown here.

APPROACH TO DEVELOPING AND USING NEEDED STRUCTURE

- DETERMINE ECHELONS NEEDED TO DEFINE HIERARCHY
- FOR EACH ECHELON:
  - DEFINE COMBAT MISSIONS
  - DEVELOP REQUIRED COMBAT FUNCTIONS
  - RELATE COMBAT FUNCTIONS TO MOVEMENT CHARACTERISTICS
- COUNT NUMBER OF LINKS RELATING MOVEMENT CHARACTERISTICS TO COMBAT MISSIONS TO ESTABLISH POTENTIAL COUPLING
- APPLY MILITARY JUDGMENT TO DETERMINE RELATIVE STRENGTH OF EACH COUPLING - PROVIDES CRUDE INDICATOR AS TO IMPORTANCE
- USE THIS TAXONOMY TO:
  - CLASSIFY EXISTING LITERATURE
  - DETERMINE MEANINGFUL TRADEOFFS
  - FIND GAPS
  - ASSIST IN PRIORITIZING FURTHER EFFORT

The first two steps are self-explanatory. The third and fourth comprise the construction of our rough route map. After we have established the possible links between those movement characteristics that describe mobility performance and combat missions, we can count those links to get a first assessment as to the possible contributions of mobility to mission performance. However, some of these couplings will be very slight; others very strong. In the absence of data for the unexplored regions to tell us what this sensitivity really is, we had to fall back on judgment, but we could use the structure already established to structure this judgment and make a zero order estimate as to the probable areas of highest payoffs that should be explored first. After such a taxonomy has been constructed, the last step is of course to apply it for its intended purpose.

Before going on to describe the taxonomy it is probably well to dispose of the always bothersome question of a definition. Our initial literature search disclosed virtually as many definitions of tactical mobility as authors. Hence, one of the tasks assigned to the working groups at the Mobility Conference was the definition of tactical mobility at each of three echelons. Their definitions are shown on this slide.

DEFINITION

ONE-ON-ONE: CONTROLLED MOVEMENT OF A (COMBAT) VEHICLE ON BATTLEFIELD TO ACHIEVE MISSION

SMALL UNIT: ABILITY OF COMBAT UNIT TO MOVE FROM POINT TO POINT -- AS REQUIRED TO ACCOMPLISH MISSION --

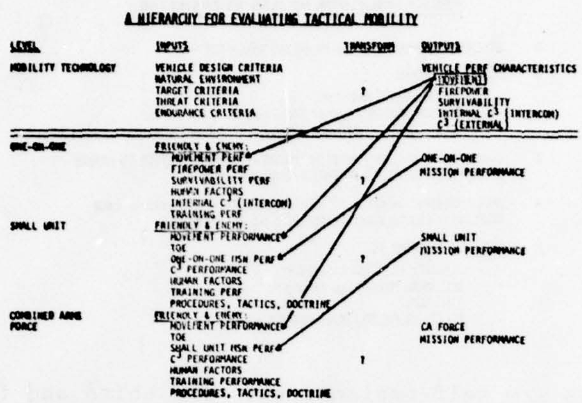
COMBINED ARMS FORCE: ABILITY TO MOVE AND SUSTAIN RELEVANT COMBAT POWER AT PLACE AND TIME OF CHOICE

OPERATIVE WORDS: MOVE COMBAT POWER MISSION

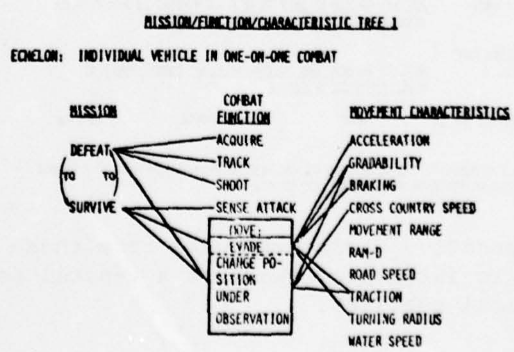
TACTICAL MOBILITY MAY BE DEFINED AS THE MISSION-RELATED MOVEMENT OF A COMBAT VEHICLE OR FORCE ON OR NEAR THE BATTLEFIELD

Also shown are the operative words extracted from these three definitions and an attempt to integrate them into a general definition of what we mean by tactical mobility.

The first step in our approach to building a taxonomy was a determination of the echelons that should comprise the hierarchy.

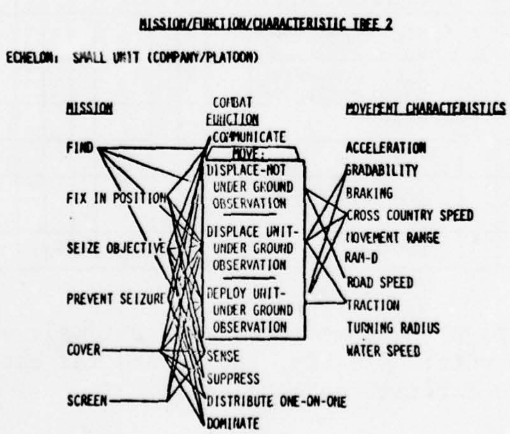


A hierarchy which can lead us from tactical mobility to combat effectiveness is shown at this slide. Fundamental to the whole problem and underlying all the rest is the basic echelon of mobility technology. This echelon is concerned with the transformation of vehicle design criteria, in conjunction with the anticipated natural and man-made environmental factors, into individual vehicle performance characteristics. These performance characteristics include movement, firepower, survivability, and others and are the basic inputs to investigations at higher echelons. However, this investigation is not concerned with mobility technology, per se; the problem is one of relating mobility to combat performance in an effort to determine its value to the military force. We can, therefore, ignore this first echelon except as it provides inputs to the remaining required transformations. The next three echelons are listed below the double line divider. The figure portrays the three identified echelons in terms of the transformations required to convert the movement performance inputs into outputs ending finally with the mission performance of the combined arms force. The figure indicates that the movement performance characteristics developed at the underlying level of mobility technology provide inputs to all three of the higher transformations. Also indicated is the notion that the outputs of each of the lower transforms at One-on-One and small unit levels provide inputs in terms of mission performance to the next higher echelon.



The tree relationship between mission, function, and movement characteristics for the lowest echelon, One-on-One, is depicted here. This applies only to an individual vehicle once it is engaged in one-on-one combat. Its missions at this stage are simple, but interrelated as indicated: to defeat the enemy weapon (whether this results from killing, rendering incapable of further combat, or causing it to surrender) and to survive. Each is necessary for the accomplishment of the other. Although labeled One-on-One, this slide will also serve to cover the altogether too frequent situation of "one-on-N" for which the mission and functions remain the same.

To accomplish these missions, however, the vehicle must be capable of performing a number of functions as indicated. In order to defeat the target, it must be capable of acquiring it and of tracking it if either target or vehicle are moving. It must be capable of firing at the target and of changing its own position under enemy ground observation to improve its firing position. In order to survive while it is attacking the target, it must be capable of sensing when it is being attacked, it must be able to evade enemy fire, and it must also be capable of changing its position under enemy ground observation. Of these six functions it is only the last two for which movement is both a necessary and sufficient condition, and their relationship to the ten movement characteristics is indicated. The movement characteristics shown have been referred to as a standard set. They are standard only in the sense that the same set has been applied to all three echelons. Ideally they should comprise an orthogonal set of mutually independent parameters. Although the set listed here has been boiled down from an initial list of 29 and does encompass the most important movement performance parameters we recognize that this list is not yet mutually exclusive.



This slide illustrates the relationship at the next higher echelon, the small unit, i.e., platoon or company. In strict compliance with the hierarchy that has been established, it will be noted that the combat functions performed by the small unit do not include direct attack of enemy targets except as that is subsumed into the function of distributing the fires of its component vehicles into one-on-one engagements. The functions of the small unit are those involved in management of one-on-one actions so as to accomplish the unit mission. Of the eight

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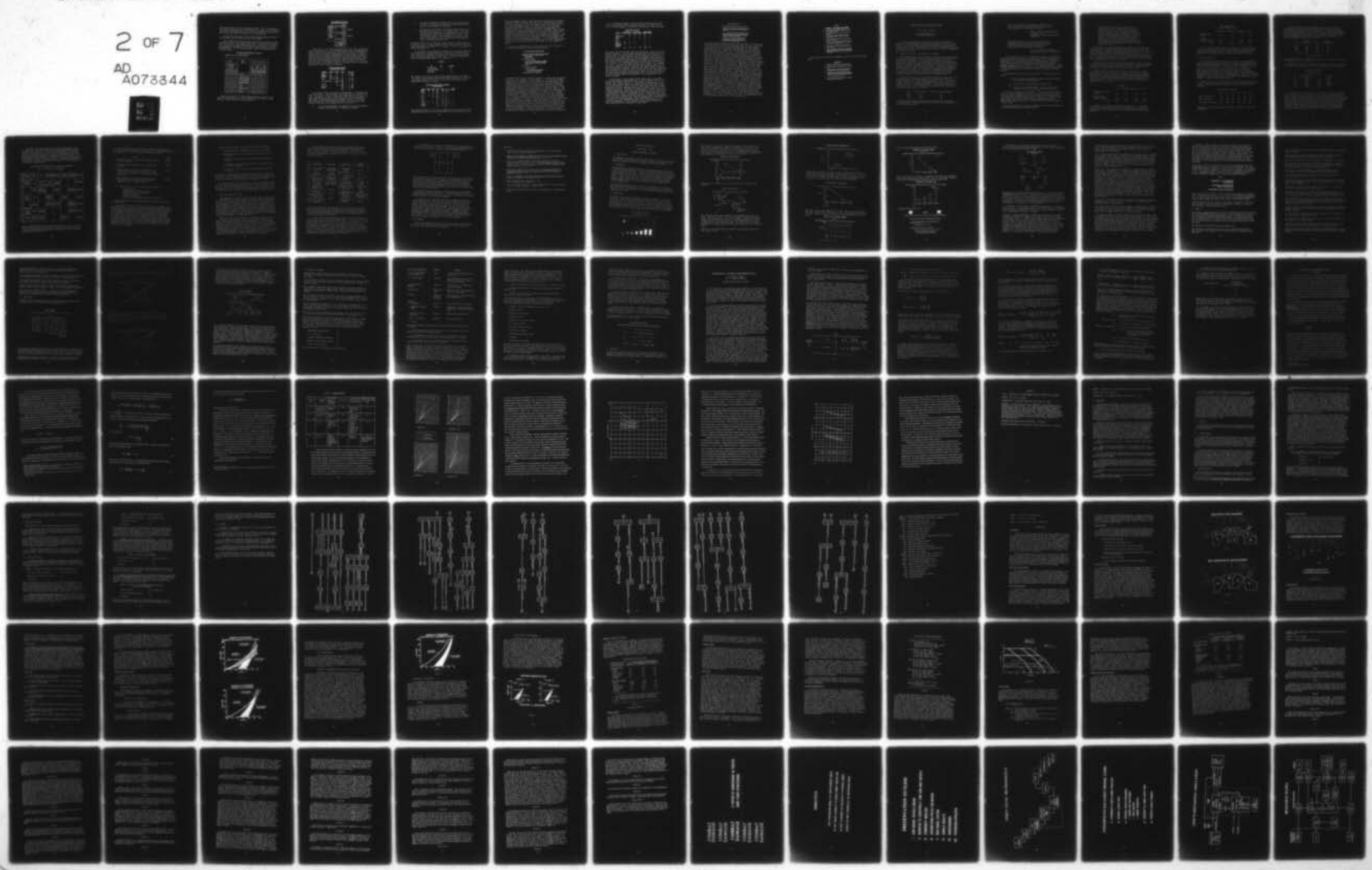
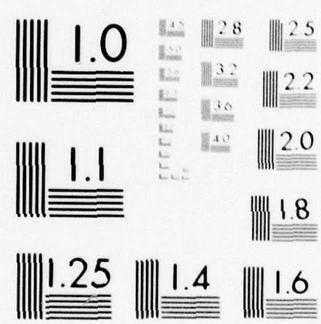




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

functions listed, only three encompass movement. Their relationship to the movement characteristics is indicated. Not shown, is the relationship of the "Distribute One-on-One" function to movement characteristics since these were already indicated in the preceding tree.

You will note how complex the interrelationship between missions and functions are becoming as we move up in echelon.

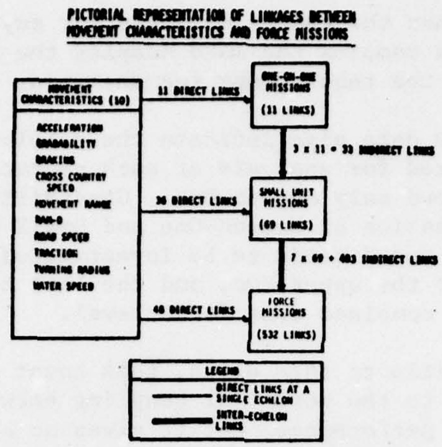
This complexity has become almost impossible to represent by this means when we get to the combined arms level. Clearly, the tree depiction is perhaps more satisfying aesthetically than useful as a means for counting the linkages between movement characteristics and mission accomplishment. For the latter purpose, a matrix representation is much more useful.

MISSION/FUNCTION/CHARACTERISTIC MATRIX 2

ECHELON: SMALL UNIT (COMPANY/PLATOON)

MISSION						COMBAT FUNCTION	MOVEMENT CHARACTERISTICS									
FIND	FIX IN POSITION	SEIZE OBJECTIVE	PREVENT SEIZURE	COVER	SCREEN		ACCELERATION	GRADABILITY	BRAKING	CC SPEED	MOVEMENT RANGE	RAM-D	ROAD SPEED	TRACTION	TURNING RADIUS	WATER SPEED
X	X	X	X	X	X	COMMUNICATE										
X				X	X	DISPLACE-NOT UNDER GROUND OBSERVATION				X			X			
X	X	X	X	X	X	DISPLACE UNIT-UNDER GROUND OBSERVATION		X		X				X		
	X	X	X	X		DEPLOY UNIT-UNDER GROUND OBSERVATION		X		X				X		
X	X	X	X	X	X	SENSE										
	X			X		SUPPRESS										
		X	X	X		DISTRIBUTE ONE-ON-ONE										
		X	X			DOMINATE										

This slide portrays the same linkages previously shown in tree format for the small unit. Clearly, the Xs are far easier to count than the lines on the earlier representation.



This slide is a pictorial representation of the link count made on the three matrices, i.e., for One-on-One, small unit, and combined arms force. You will note that some of the links are direct from movement characteristics to mission accomplishment at each echelon. Others are indirect and result from incorporation of one-on-one mission outcomes into small unit performance through the "Distribute One-on-One" combat function and the incorporation of small unit outcomes into combined arms force mission outcomes through the "Allocate Small Unit" function at force level. The cascading effect of the lower links as they support higher unit combat functions is apparent.

POTENTIAL EFFECT OF MOVEMENT CHARACTERISTICS ON MISSION ACCOMPLISHMENT - BY ECHELON

MOVEMENT CHARACTERISTIC	ONE-ON-ONE FACTOR	SMALL UNIT FACTOR	CA FORCE FACTOR		NUMBER(FRACTION)
ACCELERATION	x1	x3	x7	=	21 (.039)
BRAKING	x1	x3	x7	=	21 (.039)
TURNING RADIUS	x1	x3	x7	=	21 (.039)
GRADABILITY	x3	x3	x7		
	-	x10	x7	=	133 (.250)
TRACTION	x3	x3	x7	=	133 (.250)
		x10	x7		
CROSS COUNTRY SPEED	x2	x3	x7	=	140 (.263
	-	x13	x7		
	-	-	x7		
ROAD SPEED	-	x3	x7		
	-	-	x14	=	35 (.066)
MOVEMENT RANGE	-	-	x7	=	7 (.013)
RAM-D	-	-	x14	=	14 (.026)
WATER SPEED	-	-	x7	=	7 (.013)
			TOTAL	=	532

The results of this calculation are summarized in a different manner on this slide. The ten movement characteristics are listed at the left. The number of links to missions is shown under each echelon. A blank indicates no coupling to the missions of the lower echelon, but that there is independent coupling to higher echelons to the right. The totals and the corresponding fractions are at the extreme right. Several conclusions can be drawn from such a structure.

- It certainly highlights the complexity of the relationship of movement characteristics to mission performance.

- The higher the number of links for any given characteristic the more complex the more complex the relationship and the greater the requirement for analysis.

- The same data also indicate the echelons that need to be investigated for analysis of each characteristic. The first three need only One-on-One. Gradability and traction need investigation at One-on-One and Small Unit levels. Cross country speed needs to be investigated at all three, road speed at the upper two, and the last three characteristics only at combined arms force level.

As stated in the title to this slide, this count of the links gives us an initial idea as to the potential coupling between movement characteristics and mission performance, but it gives no clue as to how important these links might be.

In the absence of quantification adequate for sensitivity analysis, it was necessary to apply judgment as to the value of each potential link. This was accomplished by querying six resident military experts as to the relative importance of each link. A three-tier scheme was used for recording these judgments as indicated.

LINK EVALUATION

BASIS	RANK	VALUE ASSIGNED
VERY STRONG RELATIONSHIP	3	1.0
NORMAL STRENGTH RELATIONSHIP	2	0.5
WEAK RELATIONSHIP	1	0.25

The assigned value for each link was then substituted for the simple "X" entries in the Movement Characteristic/Mission Matrices of the kind I previously showed so that now we could add up the assigned values rather than the number of links.

PAYOFF POTENTIAL OF MOVEMENT CHARACTERISTICS TO COMBINED ARMS FORCE MISSION ACCOMPLISHMENT

MOVEMENT CHARACTERISTIC	ONE-ON-ONE FACTOR	SMALL UNIT FACTOR	CA FORCE FACTOR		RELATIVE VALUE	FRACTION	RANK	BASED ON LINK COUNTS
TRACTION	x3	x2 x0.5	x4.75) x4.75)	=	68.08	.3019	1	2
CROSS COUNTRY SPEED	x2	x2 x0.75	x4.75) x4.75) x2.25)	=	67.50	.2965	2	1
GRADABILITY	x1.5	x2 x4.25	x4.75) x4.75)	=	34.44	.1530	3	3
ROAD SPEED		x1.5	x4.75) x5)	=	12.13	.0538	4	4
RAM-D			x10	=	10.00	.0438	5	6
ACCELERATION	x1	x2	x4.75	=	9.50	.0416	)	
BRAKING	x1	x2	x4.75	=	9.50	.0416	) 6,7,8	5,6,7
TURNING RADIUS	x1	x2	x4.75	=	9.50	.0416	)	
MOVEMENT RANGE			x5.5	=	5.50	.0241	9	9
WATER SPEED			x1.125	=	1.125	.0049	10	10

The assigned values for each link are summarized on this slide for each movement characteristic in the same format as in the earlier slide that

showed the number of links. This table is the primary tool for assessing what is known, where the gaps are and for establishing priorities for filling the gaps. Please note again, though, that this is only a zero order approximation as to the relative value of the movement characteristics here considered to the mission accomplishment of a combined arms force. It is being used only to determine which of these links should be explored and quantified first by means of more precise techniques. As soon as such results are available, they should, of course, be substituted for the structured judgment portrayed here. The movement characteristics have been rank ordered by their apparent significance for force mission accomplishment. It is interesting to observe that the rank ordering when weighted does not differ substantially from that we got by considering only the number of links (column at right).

We turn our attention now to the application of this taxonomy to the search and analysis of the available literature.

APPLICATION OF TAXONOMY FOR EVALUATION OF LITERATURE

- CLASSIFY REFERENCE ACCORDING TO TAXONOMY ELEMENTS (ECHELON, MOVEMENT CHARACTERISTIC, COMBAT FUNCTION, MISSION) TO DETERMINE:
  - POTENTIAL PRESENCE
  - DELIBERATE COVERAGE
- USE LINKAGE CONCEPT TO DETERMINE:
  - LINKS POTENTIALLY PRESENT
  - LINKS DELIBERATELY ADDRESSED AND THOROUGHNESS OF COVERAGE
  - KIND OF INFORMATION (PERFORMANCE MEASURES, EFFECTIVENESS MEASURES, PERFORMANCE DATA, QUANTIFICATION TECHNIQUES, TRADEOFFS, GAPS)
- SORT REFERENCES:
  - LINKS ADDRESSED AT HIGH VALUE
    LINKS ADDRESSED AT LOW VALUE
  - REFERENCES WITH NO LINKS BUT:
    PROVIDE INFO ON TECHNICAL BASE (PERFORMANCE)
    PROVIDE INFO ON EFFECTIVENESS MEASURES
- DETERMINE COVERAGE RELATIVE TO POTENTIAL PAYOFF

As shown on this slide we used the taxonomy to classify every reference according to the elements of the taxonomy, i.e., by echelon, movement characteristic, combat function and mission to determine whether these elements were all present, so that one or more links was potentially considered and then to assess the thoroughness with which each potentially present link was in fact covered. To do this we used a coding scheme which enabled us to do the sorting on a desk top computer. The thoroughness of coverage was indicated by a three-tier scheme much like that used for assessing the importance of the links, i.e., thorough coverage, median coverage, and marginal coverage. A fourth category, zero coverage of a potential link enabled us to count "lost opportunities". We also determined and coded the kind of information provided by each reference, i.e., did it contain performance measures, performance data, quantification techniques, trade-offs, gaps, etc. This then permitted us to sort the body of literature by links addressed at high value, links addressed at low value and references which did not close links but provided information either on the technical mobility base (mobility performance) or on effectiveness measures that could be used for evaluating changes in mobility performance. Such effectiveness measures were of course not specifically mobility related, but would be

useful for measuring changes in combat effectiveness resulting from changes in performance of any kind by the force. The result of this, insofar as link coverage is concerned, is portrayed on this next slide.

WEIGHTED COVERAGE vs PAYOFF POTENTIAL

MOVEMENT CHARACTERISTIC	ONE-ON-ONE INDEX OF PAYOFF POT'L	INDEX OF W'TD COV'G	SMALL UNIT INDEX OF PAYOFF POT'L	INDEX OF W'TD COV'G	COMBINED ARMS FORCE INDEX OF PAYOFF POT'L	INDEX OF W'TD COV'G
TRACTION	1	18	6	3	30	
CROSS COUNTRY SPEED	1	22	6	8	30	6
GRADABILITY	1	2	3	2	15	
ROAD SPEED			1	2	5	9
RAM-D					4	2
ACCELERATION	0.5	14	1		4	
BRAKING	0.5	2	1		4	
TURNING RADIUS	0.5	8	1		4	
MOVEMENT RANGE					2	1
WATER SPEED					0.5	
	4.5	67	19	15	100	18

This slide lists the movement characteristics in the order of their potential importance of force mission accomplishment as indicated on the earlier slide. At each echelon is shown an index that indicates the relative index of payoff potential for each movement characteristic and also another index that shows the coverage afforded by the literature where that coverage has been weighted to recognize the thoroughness of the coverage. It is immediately obvious that the bulk of the coverage is at the one-on-one level while the bulk of the payoff is at combined arms level. This does not mean that the lower echelon research is in any sense unneeded or wasted. Obviously, you cannot embark on measuring the higher level payoffs until the lower levels have been quantified, but it does point out what still has to be done. By the same token it also shows which movement characteristics that have high potential payoff have not been adequately investigated, e.g., gradability, road speed, and RAM-D.

To this point, I have ignored another major input to the study, the Tactical Mobility Working Meeting, a three day session held at the National War College, 26-28 July. The meeting objectives were to develop a better understanding of the qualitative and quantitative value of tactical mobility. The meeting was structured around three working groups which focused separately on one-on-one combat, small unit, and combined arms force. Following an opening general session, these groups developed assessments which were later presented to the full group at a closing session. The issues addressed by each working group for its assigned echelon included: performance measures, trade-offs, MOEs, quantification means, quantification analyses that may have been accomplished, data, testing, and analysis gaps, and recommendations for future work. I cannot do more than summarize briefly their deliberations in the short time available, but the principal problem areas identified by these deliberations are capsulized on this slide.

BASIC PROBLEM AREAS UNCOVERED

- INADEQUATE EMPHASIS ON QUANTIFYING THE VALUE OF TACTICAL MOBILITY.
- MANY TRADEOFFS BETWEEN MOBILITY AND OTHER PERFORMANCE CHARACTERISTICS NEED INVESTIGATION (FIREPOWER, SURVIVABILITY, C^3, INTELLIGENCE, HUMAN FACTORS).

  TAXONOMY WOULD NEED EXTENDING TO ASSESS RELATIVE VALUE.
- MOEs AT SMALL UNIT LEVEL TO INCLUDE OTHER DIMENSIONS OF MISSION PERFORMANCE (AREA EXCHANGE AND TIME) IN ADDITION TO EXCHANGE RATES. WIDER RANGE OF SCENARIOS NEEDS INVESTIGATION.
- LARGE VOLUME OF TEST DATA HAS NOT BEEN ADEQUATELY ANALYZED.
- NO PREDICTIVE MODEL OF "BLOCK TIME" EXISTS - FUNDAMENTAL GAP IN INPUTTING MOBILITY INTO EFFECTIVENESS MODELS.

All groups recognized that the bulk of the past effort and literature concerned mobility technology rather than tactical value. All groups recognized that trade-offs between mobility and other performance characteristics, e.g., firepower, survivability, C^3, intelligence, needed more emphasis. Human factors is another important but inadequately addressed trade-off area. In this connection the taxonomy that I have described is inadequate and would have to be extended to provide a more solid basis for evaluating the potential payoff from trade-offs and which, therefore, should be addressed first. The small unit group recognized the inadequancy of most of the MOEs that have been used at that level which have concentrated on exchange ratios and ignored the other elements of mission accomplishment. A wider range of scenarios also needs to be investigated. Another problem area identified is the large volume of existing test data that has been inadequately analyzed. Application of the taxonomy directly to the test data, rather than to reports about the test data, would be one way of addressing this problem. Finally, a serious gap is the matter of relating individual vehicle mobility to the time required to move larger units from point A to point B. Borrowing a term from the transportation analysis literature, the resulting average speed with which major units can be moved is called "block speed". This speed is of course computed by dividing the distance actually traversed by the time required from causative event (enemy action or friendly initiative expressed as a decision) to completion of the move up to the point that the assigned mission can be initiated. Although the literature does contain planning factors for use in estimating these times, no predictive models exist which could be used to calculate the effect on block time of an increment in mobility or for determining sensitivity to mobility factors. Clearly, block time is a function of many other parameters to include intelligence, C^3, staff planning procedures, road congestion, etc. Lack of such a model is seen as a fundamental gap in our understanding of the value of tactical mobility.

FINDINGS

- GOOD COVERAGE: MOBILITY TECHNOLOGY - MOBILITY PERFORMANCE
  POOR COVERAGE: MOBILITY PERFORMANCE - COMBAT EFFECTIVENESS
- PAST AND CURRENT INVESTIGATIONS DOMINATED BY ONE-ON-ONE SURVIVABILITY AND HARDWARE PERFORMANCE
- COMBINED FIREPOWER/MOBILITY INVESTIGATIONS TEND TO CONCENTRATE ON FIREPOWER
- NO STRUCTURAL BASIS FOR TRADEOFF ANALYSES BETWEEN DIFFERENT KINDS OF PERFORMANCE (MOBILITY, FIREPOWER, C^3, INTELLIGENCE, HUMAN FACTORS, ETC.)
- LITERATURE FINDINGS CONTRADICTORY ON QUESTION OF ARMOR VS MOBILITY TRADEOFF TO GET SURVIVABILITY
- TAXONOMY IS USEFUL FOR PRELIMINARY STRUCTURING OF FURTHER EFFORT (TRADEOFFS AMONG MOVEMENT CHARACTERISTICS AND ECHELONS) BUT NEEDS TO BE EXPANDED TO OTHER PERFORMANCE FACTORS
- EXPANDED TAXONOMY SHOULD BE APPLIED TO THE EXISTING DATA BASE
- IMPACT OF MOBILITY ON MISSION PERFORMANCE ABOVE ONE-ON-ONE LEVEL HAS BEEN NEGLECTED
- TRUISM THAT INCREASED RANGE (ARTY, RADAR) ALWAYS SUBSTITUTABLE FOR MOBILITY NEEDS EXAMINATION - MAY BE TRUE ONLY OVER LIMITED DOMAIN
- PREDICTIVE MODEL FOR DETERMINING TOTAL TIME TO MOVE COMBAT FORCE IS URGENTLY NEEDED

The results of the study are summarized on this and the succeeding slide.

RECOMMENDATIONS

- EXPAND MOBILITY TAXONOMY TO INCLUDE FACTORS OTHER THAN MOBILITY
- APPLY EXPANDED TAXONOMY TO TESTING AND OTHER ORIGINAL SOURCE DATA BASES
- USE EXPANDED TAXONOMY TO GUIDE RESOLUTION OF MOBILITY/ARMOR vs SURVIVABILITY ISSUE AND OTHER BENEFICIAL TRADEOFF RESEARCH
- EXISTING MODELS AT ALL LEVELS BE IMPROVED TO SENSITIZE COMBAT OUTCOMES TO MOBILITY PERFORMANCE THAT IMPACTS ON TACTICAL MISSION PERFORMANCE - PROBABLY WITHIN TRADOC MODEL IMPROVEMENT PROGRAM
- A "BLOCK SPEED" MODELING EFFORT BE INITIATED
- SMALL UNIT FREE MANEUVER TESTING PROGRAM BE INITIATED TO EXAMINE ONE-ON-ONE RESULTS IN SMALL UNIT CONTEXT

GRADUATE EDUCATION IN SUPPORT OF ORSA

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This paper is addressed to the subject of graduate education in support of the ORSA alternate specialty in the Army. Attention is first focused on the broader issue of fully-funded graduate education in the military, within which ORSA competes for a share of the limited resources. The Army ORSA specialty is then addressed in terms of assets, requirements, and trends in education.

A. Graduate Education in the Department of Defense

ORSA (Engineering) is the second most critical education field within the Army, where the term critical is defined in terms of the deficit of assets minus requirements. To understand the reasons for this, it is necessary to realize the constraints under which the Civil Schools Branch must work in seeking to remedy this problem. The Army, and all the Services, are severely constrained in the number of officers it can input to graduate education. When all specialties are considered, the Army has about 5000 positions which are validated as requiring graduate education for satisfactory performance. Against this requirement, the Army is authorized only about 800 students in degree-seeking, fully-funded, graduate education; an AOB or average on board of 800 officers.

Since FY 1974, AOB across all services has been cut nearly 50%. The reductions began in the post-Southeast Asia period with a 20% cut by Congress in the FY 1974 Defense Appropriation Bill. As a result, inputs to ORSA-Engineering in recent years have been only about 30 officer students per year. Thus ORSA-Engineering is the second most critical subspecialty today. Total graduate officer production for the Army is estimated to have fallen as follows(1):

Year	Grad. Off. Prod'n	Prod'n % of End Strength
1972	817	.67
1975	728	.71
1978	552	.56

What forces or factors have produced the reductions in officer graduate education? Opposing sides of the issue are well represented in the following quotations.

"The data available to the Committee indicates that a large portion of the graduate education program is not really essential to the military services."

Report of the House Appropriations Committee (2)
Department of Defense Appropriation Bill, 1976

"The Congress ought to realize that in view of the dependence of the military in science and technology in this day and age this kind of investment in higher education is absolutely essential."

Jerome B. Weisner[3], President
Massachusetts Institute of Technology

At this point the critics are winning the argument. Their doubts may be categorized as follows: (1) that the "system" is not working as designed, and (2) that benefits do not outweigh the costs involved. The first issue is readily analyzed and the system modified as necessary. The second issue begs for a cost/benefit analysis of the value of graduate education, and this has proven to be extremely difficult. Indeed, even the critics have found it easier to note problems with the operation of the system rather than deal with the benefits of graduate education question.

The 1970 General Accounting Office report[4] raised the following points:

(1) the criteria for identifying graduate education positions were too broad and permissive;

(2) the criteria were inconsistently applied; and

(3) officers with graduate degrees in many cases were not assigned to positions requiring specialized education.

The Office of Management and Budget[5] notes that service requirements for graduate degrees for similar career fields significantly differ from one another, lending credence to the problem of the criteria being too permissive and inconsistently applied. They note, for example, that where the Air Force has 697 billets requiring graduate education to support ROTC instructor positions, the Army has no validated positions in the ROTC field.

Major congressional concerns are summaried in the following from the FY 1974 House Armed Services Committee Report:

"The Committee is not convinced that all these positions do, in fact, require the holding of advanced degrees. Nor is the Committee convinced that the incumbents need be military officers educated at government expense as opposed to civilians who have acquired their degrees prior to being employed. The Committee recognizes that there is a valid need for a well-educated officer force but rejects the concept of advanced education per se as a benefit which must be available in order to attract and retain officers."(5)

The report of the House Appropriations Committee for FY 1976 took a similar position. The Committee pointed out that only "60% of the Army's, 37% of the Navy's and 65% of the Marine Corps positions are at any one time filled with personnel holding the appropriate specialty or a specialty in a related discipline."(6) For the Air Force they estimated a 50% fill rate for officers with graduate education. Again, since so many positions were not being held by officers with graduate degrees, the overall validity of the requirement was brought into question.

Since FY 1974 the Services have taken significant measures to improve the operation of the system. The Army, in particular, has achieved strong control of the system. Education is authorized only for AERB validated requirements, and subsequent utilization is now nearly 100%.

On the question of the value of graduate education, the factors of promotability and retention have been studied -- not so much, I think, because they are critical factors, but rather because they are studyable. With regard to promotion and graduate education, the following indicates that graduate education significantly enhances promotion potential. In reality, however, it is not clear which cause and effect relationship is demonstrated by this analysis.

U.S. ARMY(7)

	Lt. Col.	Promotion	Not Lt. Col.	Pop'n
Majors with Graduate Degrees	4670	.86	762	5432
Majors without Graduate Degrees	3683	.66	1930	5613
Total	8353	.75	2692	11,045

Retention is an inherently more satisfying argument for graduate education, but cause and effect is again a problem. In any event, the following data are quite significant in relating graduate education with retention.

ARMY RETENTION (8)
U.S. Army: 1965 Year Group

	In Service	Retention	Resigned	Pop'n
With Graduate Degree	738	.91	76	814
Without Graduate Degree	956	.57	708	1664
Total	1694	.68	784	2478

Let me close this section with a challenge to the analysts present that a good, solid analysis of the value of graduate education in dollar and cents terms is sorely needed. Further, without such quantitative justification of graduate education, further reductions are possible.

B. The ORSA Specialty

In focusing now on graduate education for ORSA, it is perhaps appropriate to note immediately that the Army recognizes two ORSA specialties: ORSA - Engineering and ORSA - Business. A simplistic explanation of the differences in these programs is as follows. ORSA - Engineering is the more quantitative program. It strongly emphasizes probability, statistics, data analysis, optimization techniques, and computing. ORSA - Business is a management program with emphasis on quantitative methodology and techniques. As a mangement program, ORSA - Business also includes theories of organization and management, and elements of financial management. Both programs, Engineering and Business, additionally share emphasis of economics and systems analysis.

In the Army, and all the Services, officers are educated to serve in positions validated as requiring graduate education for satisfactory performance. The data below give a history of U.S. Army ORSA validated positions.

AERB VALIDATED POSITIONS

	1969	1970	1972	1973	1974	1976
ORSA - Engineering	290	261	277	233	258	318
ORSA - Business	255	220	229	183	193	190
Total Army Validations	6489	6329	6916	6394	5556	4985

From here on, I will be primarily interested in the ORSA - Engineering discipline.

Actual graduate education inputs depend upon both the validated requirements and upon the assets available to fill validated positions. The Army uses a factor of 2.4 (times the number of validated requirements) to get actual requirements. The 2.4 factor reflects career progressions that include primary specialty focus, other training and education, service in joint commands, etc. The assets vs. requirements situation for ORSA - Engineering is presently as follows:

Rank	Actual Requirements	Assets	Assets Requirements
COL	43	19	.44
LTC	252	61	.24
MAJ	338	109	.32
CPT	130	60	.45
Total	763	249	.33

(as of 18 July 1977)

The figures in the last column indicate pretty clearly why ORSA - Engineering is considered a critical discipline.

To improve the asset vs. requirement situation we see ORSA - Engineering commanding an increasing share of the useably graduate education quotas.

ORSA - Engineering

Fully-Funded Quotas

FY	QUOTA/TOTAL QUOTAS	%	UTILIZATION
74	36/491	7.3	25/69%
75	29/347	8.4	16/55%
76	23/277	8.3	17/74%
76T	5/49	10.2	5/100%
77	28/297	9.4	27/96%
78	39/312	12.5	

U.S. Army ORSA - Engineering education is presently being accomplished at 16 institutions. As of 30 June 1977, there were 38 Army officers enrolled as ORSA - Engineering students in these 16 institutions, with the largest number enrolled in the program at the Naval Postgraduate School (NPS). While the nature of the programs differ from school to school, I can speak with authority about only the NPS program. Those interested in more information about other programs are referred to the brochure, "Education Programs in OR/MS," published jointly by the Operations Research Society of America and The Institute of Management Sciences, and available from the ORSA Business Office, 428 East Preston Street, Baltimore, MD 21202.

The ORSA - Engineering program at the Naval Postgraduate School has within the last two years been reluncantly shortened from eight quarters to six quarters. In an effort to accommodate the reduced AOE levels, it has become Army policy that the maximum length of graduate education programs, regardless of discipline, will be 18 months. The NPS program stresses the basics of mathematics, probability and statistics, optimization, computing, economic analysis, and applications modelling -- all strongly oriented to the problems of Defense. In time sequence, the curriculum is as shown below.

NPS OPERATIONS RESEARCH/SYSTEMS ANALYSIS CURRICULUM

FOR U.S. ARMY ORSA - ENGINEERING

Q	SPECIALIZATION	PROB & STAT	MATH	COMPUTER SCIENCE	OPTIMIZATION	STOCH MODELS	SYSTEMS ANALYSIS	SEMINARS
1	INTRO MILITARY OR	PROB	TOPICS IN CALCULUS	INTRO TO COMPUTERS	LINEAR ALGEBRA			SEMINAR
2		PROB & STAT	MULTI-VARIABLE CALCULUS		LINEAR PROG		MATH ECONOMICS	SEMINAR
3	OR IN ARMY SYSTEMS	STAT		COMP'L METHODS FOR OR		STOCH MODELS		SEMINAR
4		DATA ANALYSIS		SYSTEMS SIMULAT'N	NONLINEAR PROG		UTILITY & RESOURCE ALLOC'N	SEMINAR
5	EXP TOUR OR OPTION COURSE	THESIS	OPTION COURSE				SYSTEMS ANALYSIS	SEMINAR
6	THESIS	OPTION COURSE	OPTION COURSE			STOCH MODELS II		SEMINAR

One can readily identify the mathematical foundations which support the entire curriculum, the year of work in probability statistics and data analysis, the computing and simulation, optimization, systems analysis, and applied modelling courses.

Let me highlight just one course, OA 4656 "OR in Army Systems." The course focuses on quantitative analysis support in weapons evaluation and acquisition. A very terse course outline is as follows.

	TOPIC	TIME
1.	The Acquisition Cycle & Decision Processes including the role of COEAs	1 week
2.	The COEA process, TRADOC guidelines, examples and pitfalls	3 weeks
3.	Combat modelling, analytical and simulation, unit to theater levels, models in use today -- Army Mobility Model, Bonder IUA, Division Battle Model, JIFFY, etc.	4 weeks
4.	Student prepared critiques/case studies of recent major system COEAs, examples XM-1, HELLFIRE, BUSHMASTER, GLGP, Scatterable Mines	3 weeks

The option courses are selected from the following list:

* Combat Models
* Quantitative Analysis of Tactics
* Operational Test and Evaluation
* Campaign Analysis
* Design of Experiments
* Reliability and Weapons Systems Effectiveness.

Other option choices from Systems Analysis or Human Factors areas are also possible.

An experience tour wherein the officer student is assigned to an operating analysis shop for a six week period during the academic program was mandatory in the program. With the experience tour and the thesis to both demonstrate the student's ability to effectively apply the tools and techniques of analysis to significant problems, NPS could pretty well assure that its graduates were immediately capable of performing as competent operations analysts in validated positions. Experience tours were taken by Army officer students in such organizations and the Concepts Analysis Agency, the Combat Development Experimentation Command, the TRADDC Systems Analysis Activity, the Armor Agency, etc. With the compression of the program to six quarters, the experience tour is now optional for Army students.

Some recent Army officer thesis topics include the following.

* Scatterable Mines: Dispersion, Detection, and Avoidance

* APL Histogram, Density Estimation and Probability Plotting Routines

* Generation and Analysis of Parameterized Terrain for Land Combat

* A Simulation of Field Artillery Battery in the Defense With and Without TACFIRE

* An Analysis of Major Training Area Operations Conducted by V Corps

Note that the second thesis listed was completed by an officer slated to teaching in the Mathematics Department at the Military Academy. The last topic listed was instigated, as you may suspect, by General Starry, and the two authors took their experience tour with the V Corps.

The Operations Research curriculum at the Naval Postgraduate School was the first in the country, with the first students entering in 1951. Our first Army officer was graduated in 1964. To date, there have been 212 Army graduates of the ORSA - Engineering program at Monterey. In 1976, the first Army officers entered the NPS ORSA - Business program.

C. Future Developments in ORSA

ORSA programs have evolved over time and will always continue to do so. The McNamera era brought economics and systems analysis and changed the name of programs from OR to ORSA. Certainly, tools and techniques for performing Cost and Operational Effectiveness Analyses (COEA) are rather important to today's uniformed Army analyst. Computing has also grown in importance to the analyst. Here I am not thinking so much of the programming of large simulations or optimization models, but rather of the need for the analyst to effectively utilize interactive types of computing from his office or field location. The modern analyst should also understand data base structures and their application in everything from personnel systems to command and control.

What lies ahead? In all honesty, I do not know. There is a tiny bit of truth to the proposition that the success of the Operations Research discipline will put us all out of business. Let me explain that a bit. In the non-defense sector, operations research and systems analysis techniques have become exciting new tools for dealing with urban planning, health care, finance, and public policy. In engineering, optimization and stochastic processes have become important tools. As the techniques are adopted by other disciplines, there may be less demand for the OR disciplinarian. Perhaps mathematics and even statistics are examples of disciplines that have experienced this phenomena.

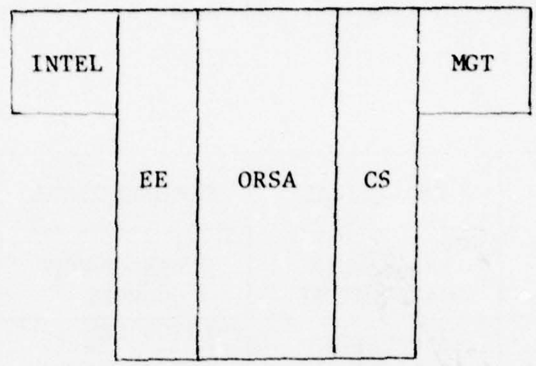
In the defense sector there are some exciting new developments which combine necessary technical disciplines with ORSA methodology to focus on specific operational military problems. At NPS there are several such new programs: Antisubmarine Warfare, Electronic Warfare, and Joint Communications, Command, and Control. Let me illustrate with the ASW curriculum.

Q	OPERATIONAL	ANALYTICAL	ENVIRONMENTAL	SYSTEMS ENGINEERING
1	SOVIET THREAT ANALYSIS	PROGRAMMING CALCULATORS	OCEANOGRAPHY SURVEY	MATH I
2	INTRO TO SONAR EQUATION	APPLIED PROBABILITY	PHYSICS REV / METEOROLOGY	MATH II
3	SEARCH, DET & LOCALIZATION	PROGRAMMING & SIMULATION	UNDERWATER ACOUSTICS	MATH III
4	ASW SYSTEMS PROJECT	DECISION AND DATA ANALYSIS	ENVIRONMENTAL FACTORS IN ASW	ELECTRONIC SYSTEMS
5	COMBAT MODELS WEAPONS EFF	INDIVIDUAL STUDY PROJECT	UNDERWATER SOUND PREDICTION	SIGNALS AND NOISE
6	HUMAN FACTORS IN ASW		ADV TOPICS UNDERWATER SOUND	SIGNAL PROCESSING
7	TACTICAL DESIGN & EVALUATION		EM WAVE PROPAGATION	SONAR SYSTEMS ENGINEERING
8	DEFENSE DECISION PROCESSES		NON-ACOUSTIC SENSORS	ELECTIVE

Clearly, Operations Research methodology and techniques are the mortor with which the physical and environmental sciences are glued together and focusedon the operational antisubmarine warfare problem. Obviously, other operationally oriented curricula with strong ORSA dependence are possible and should be anticipated.

A new program, Joint Communications, Command, and Control, began at NPS last week. The program was initiated directly and personally by the former Deputy Secretary of Defense, Mr. William P. Clements. It is a DOD program rather than a program of an individual service and the Joint Program Sponsor Group includes the Joint Chiefs of Staff, OASD (C^3I), OASD (DDR&E), OASD (MR&L), the Defense Communications Agency, the National Security Agency, and the Services. The objective of the program reads, in part, "To develop professional expertise and judgment in the areas of requirements and systems integration and the operational aspects of joint communication, command, and control (C^3) systems."

In developing the curriculum, the NPS used the following type of diagram -- the notion of a T-man -- to portray the discipline range and depth decisions inherent in the curriculum development process.



The diagram really says very little about the program but does indicate the discipline subject matter included in the program (EE is electrical engineering and communications engineering, CS is computer science, MGT is management, especially the acquisition process, and INTEL is intelligence), their relative emphasis, and the fact that operations research/systems analysis methodology and techniques are central to this operationally oriented program.

Beyond the spread of influence of ORSA methodology and techniques in operationally oriented specialties, I think there will be new or increased ORSA activity within DOD in the areas of manpower and personnel, command and control, and financial mangement.

In summary, I have tried to indicate that graduate education must compete with manpower, acquisition, R&D, and operations for its share of DOD resources. In recent years, the level of authorized officer graduate education has been reduced nearly 50%. In this climate and against growing ORSA requirements the ORSA alternate specialty in the U.S. Army has, at present, only 33% of its required number of officers educated and available for validated positions. Though both ORSA - Engineering and ORSA - Business are presently commanding increasing percentages of useable graduate education quotas, uniformed ORSA assets will continue to be a scarce resource for a number of years to come, and we should expect requirements to continue to increase.

Acknowledgement

Grateful recognition is made to the Office of Defense Education and to the U.S. Army Military Personnel Center, Civil Schools Branch, for much of the data which appears in this paper.

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3. Letter to Dr. Richard Rose, former Deputy Assistant Secretary of Defense (Education), April 27, 1973, Officer Graduate Education Study (Draft) (Office of the Assistant Secretary of Defense, Manpower and Reserve Affairs, 1973), p. 137.

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5. Office of Management and Budget, Military Officer Graduate Education (Draft) Unpublished study (1974), p. 17.

6. Report, Appropriations Committee, p. 58.

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DIVISION RESTRUCTURING

COL DONALD S. PIHL

COMBAT DEVELOPMENTS, HQ TRADOC

1. Introduction.

The purpose of the Division Restructuring Study is to develop organizations for test which best prepare the US Army to integrate into the force and maximize the potential of the new weapons systems of the 1980's.

2. Background.

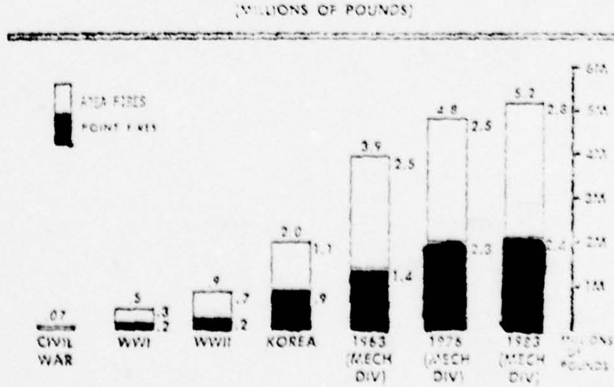
In March 1975, the Chief of Staff of the United States Army, General Fred C. Weyand instructed TRADOC to examine our divisions capability to fight a war in the future and stated -- "make sure that we are closely monitoring the development of structure and that our missions, doctrine, and organizational concepts are in concert --- and conduct a continuing 'identifiable' study". General DePuy started the process with the Division Structure Analysis (DSA), blended this effort into the Antiarmor Systems Program Review (AASPR) in 1975, and finally established a study group in his office in March 1976.

The Division Restructuring Study started by researching the October 1973 war, the US/FRG concept papers, the total tank systems study, and FM 100-5. This effort led to a historical look at battlefield trends which impact on organizational design.

3. Methodology.

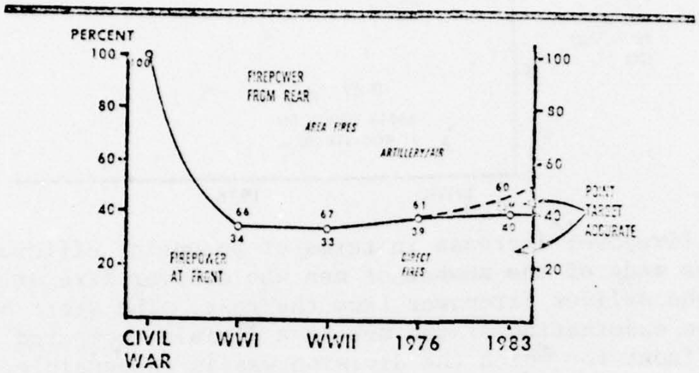
a. Trends. The study started with a historical perspective, measuring divisions from the Civil War through the current division. The start of the review of trends was the increase in the volume of firepower available to the division. The significant increase in this firepower from the Civil War in both point and area fires indicates the need to look at the methods for delivering this fire effectively. Can the current numbers of commanders with the five levels of division command handle this process effectively?

DIVISION FIREPOWER THROWWEIGHT
AREA FIRES VS POINT FIRES
(MILLIONS OF POUNDS)



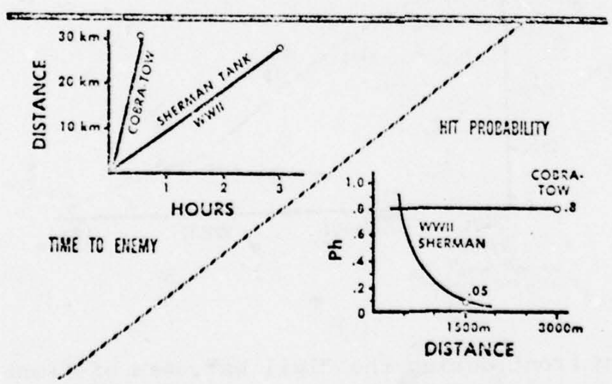
The second trend shows the change in firepower at the front from the rear. While essentially a stable ratio develops at World War I of 2/3 indirect to 1/3 direct and continues to the present, the point fire precision increases to 50% due to precision guided munitions from the rear (cannon - launched guided projectile from artillery, HELLFIRE from attack helicopters, and maverick from the Air Force)

FIREPOWER TRENDS DIVISION



Not only has the volume of fire increased, so has the mobility and lethality.

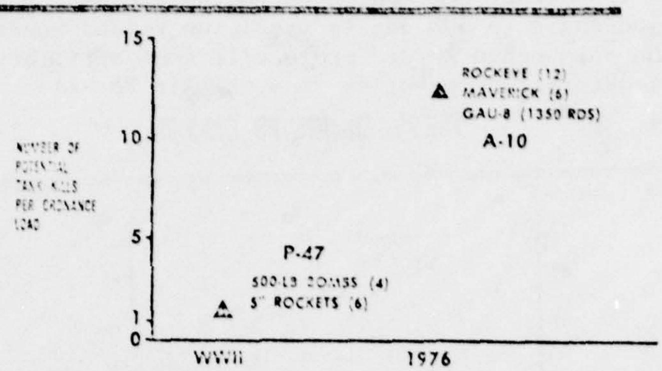
ANTI-ARMOR MOBILITY-LETHALITY



This change in mobility and lethality is also marked by a change in range. Therefore a Cobra - Tow can close 30km in 30 minutes and kill a target with .8 probability from zero to 3000m as compared to the WWII Sherman tank that took three hours to close 30km and only had at least .8 probability of kill only up to 500m. This means that as a combat multiplier, the attack helicopter can locate to the rear out of artillery range.

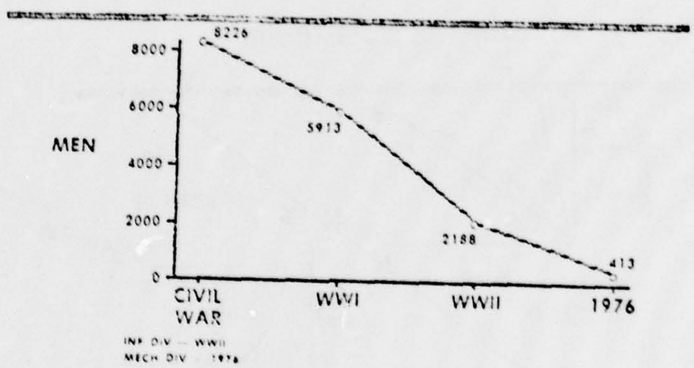
Close air support effectiveness in tank killing potential follows the same increase trend.

CLOSE AIR SUPPORT EFFECTIVENESS



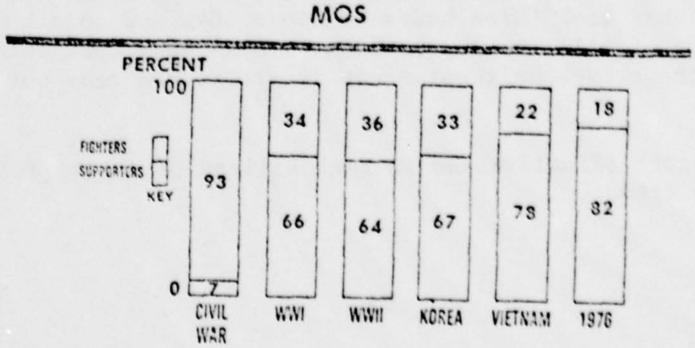
To get at the firepower increase in terms of potential efficiency, an examination was made of the number of men who deliver fire at the front versus those who deliver firepower from the rear. The start of this set of charts is an examination of the men in a division compared to the kilometers of front for which the division was/is responsible.

MEN PER KILOMETER OF FRONT DIVISION



Used here is a 1km front during the Civil War, 4km of front during WWI, 7km front for WWII, and a 40km front for the current mechanized division in Europe. When this trend is compared to those who deliver fire at the front,

DIRECT FIRE VS COMBAT SUPPORT MOS

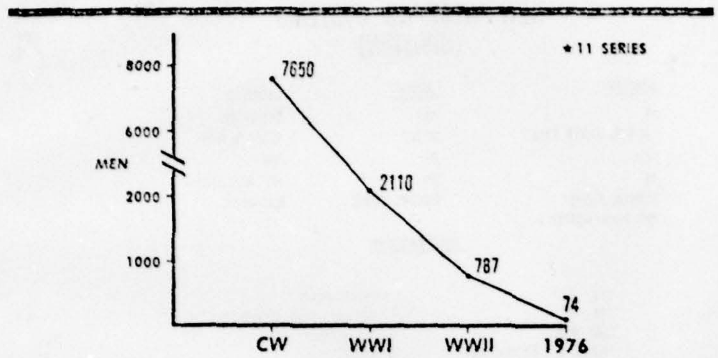


* FIGHTERS – INFANTRY ARMOR BY MOS (11) ONLY

you get 11 Series MOS personnel who man the front,

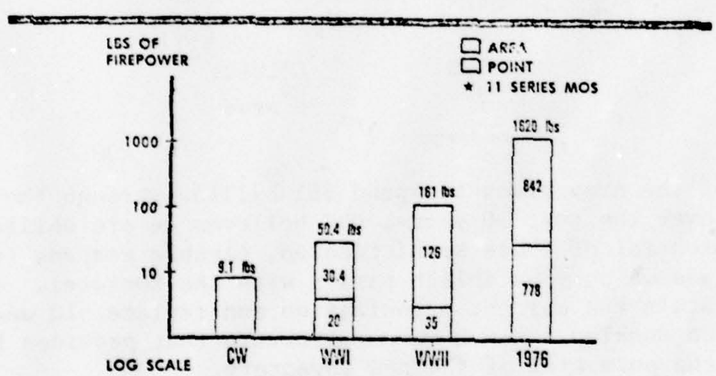
FIGHTERS* PER KILOMETER FRONT

DIVISION BY MOS



When the 74 men per km of front is compared to the chart on 5.2 million lbs of throw weight per 30 minute battle, there is a firepower potential of 1620 lbs per forward man of which he delivers roughly 50%.

FIREPOWER PER FORWARD MAN *



In summary these trends are:

XX DRSG **TRENDS** XX DRSG

- DIVISION FIREPOWER INCREASED DRAMATICALLY
- FEWER MEN FORWARD - MORE FIREPOWER PER MAN FORWARD
  - •• SUPPORTERS INCREASING
- NATURE OF FIREPOWER CHANGING
  - •• GREATER RANGE, ACCURACY, LETHALITY
  - •• *MORE FIREPOWER FROM REAR*
    - ••• PRECISION FIRES FROM REAR

b. New Weapons. The practical manifestation of these trends lead to step two of the DRS methodology, an analysis of the new weapons programmed for the Army inventory from 1980 - 1985:

NEW WEAPONS SYSTEMS
(DIVISION)

INFANTRY
IFV
W/BUSHMASTER (TBAT)
SAW
ITV
THERMAL SIGHTS
IMP 81mm MORTAR

ARMOR
XM1
M60A3
ITV
CFV
THERMAL SIGHTS

AVIATION
COBRA/TOW
SCOUT W/TADS
ASH
AAH W/HELLFIRE
BLACKHAWK

FIELD ARTILLERY
TPQ - 37
TPQ - 36
CLGP W/GLLD
TACFIRE & BTRY COMPUTER
IMPROVED RANGE:
155mm - M109A1E1/XM-198
8" - M110A1
MUNITIONS:
SCAT MINES
ICM - AT
GSRS

ENGINEER
SLUFAE
SLUMINE
CEV
UET
GEMSS
FAMECE

SIGNAL / C & C
SINCGARS
TOS
TRI - TAC

RSTA / EW
RPV
SOTAS
REMBASS
MODATS
MAGIIC
TACJAM
MULTEWS
ETC.

AIR DEFENSE
STINGER
ROLAND
AD GUN
SAM-D (PATRIOT)
TSQ-73

USAF SYSTEMS
PGM
EW SYSTEMS

Recognizing that the Army plans to spend $61 billion through the Extended Planning Annex over the next 10 years, DRS believes we are obligated to optimize the potential of these sophisticated, capable weapons (recognizing that in some cases we only establish parity with the Soviets). The issue is whether to retain the current organization and replace old weapons with new weapons or to develop a new division structure that provides better utilization of the potential of the new inventory.

c. The Problem. The problem of designing an organization to integrate, into the force, the new weapons systems of the early 1980's and to optimize their employment, results from looking at the current division in terms of tactical employment and the use of systems.

In terms of tactical employment, current doctrine calls for the company commander to integrate the combined arms team. The Antiarmor Systems Program Review (Fall 75 - Spring 76) established that a captain commanding a tank company team of 12 tanks, 4 TOW, Infantry, and mortars had 37 critical actions in the first 15 minutes of the battle. The doctrine causing the least experienced combined arms leader, with no staff, to be the agent for firepower from the rear has been criticized by other armies in terms of understanding how combined arms integration can occur at the company level. This is not to say that current experienced US Army captains are not capable considering that many are commanding their second or, in some cases, third company. But concern occurs when

considering the wartime replacement for current captains either in terms of the surviving lieutenant or a reserve component officer hastily deployed. How much experience will either of these officers have in integrating the combined arms?

It is in this area of pure versus combined arms companies that we benefited from a review of other armies, particularly in tank organizations. Both the Bundeswehr and the Israeli Defense Forces integrate combined arms at the battalion level and fight pure tank companies. Both have adopted the three tank platoon concept either completely (Israeli) or for test (FRG) because of improved fire and maneuver efficiency. We also need to understand the logistics price the Israelis pay to keep the 3-tank platoon viable in terms of crewed floats.

However, the methodology was not completely a "lessons learned" review of other armies. An assessment of US combat developments needs was also key in formulating the DRS concept. Examples of problems for the US Army where foreign models do not suffice are in artillery and mobile anti-armor systems. Here other armies depend on the United States when coping with the problem of fighting outnumbered. Recognizing that the US Army is outnumbered in artillery 7 to 1 at the point of a breakthrough attack, the study group examined ways by which the division's artillery could be increased without unreasonable overhead. Clearly this is not a total solution to the problem of fighting outnumbered, but a major move toward that problem. Equal to the problem caused by the threat is the challenge to the US Army to take advantage of new munitions (cannon launched guided projectiles, scatterable mines, and dual purpose improved conventional munitions) as well as performing new missions (counterfire, suppression of ATGM, and air defense suppression. The stark reality is that the US Army has not increased the number of tubes within a division since the Korean Conflict.

In the area of antiarmor systems, the problem is the right use of weapons. Here there are two problems, the use of TOW as a "tag along" and the extended command of tank platoons.

By placing the TOW within an infantry company, the 3000m range capability is not best used when employing the infantry for close-in battle (wooded area, built-up area). Conversely the infantry "tags along" if the TOW is sited where its 3000m range starts the antiarmor battle.

As for tank platoons, the US Army has the largest in the free world. When you examine the results achieved on Range 79, Grafenwohr, few lieutenants can control the fire of all 5 tanks on a platoon battle run. Also reportedly Fort Carson limits their platoon battle run to the three tank heavy section due to the control problem encountered by the platoon leader. We believe the Army can ill afford to organize very expensive tanks into large units where their fires are not effectively distributed. Taking the problem from a battle run into a vision of the next battlefield, SOP actions within a smaller unit in the face of smoke and electronic warfare is a viable alternative to radio command of two sections within a five tank platoon.

d. FM 100-5. Without setting a percentage of how much of this study is equipment dependent and how much is the need to adjust organization concepts to the expected lethality and intensity of the modern battlefield, it is significant that a large degree of the proposed division that follows is an adjustment to the way the Army functions and the need to change. The recent publication of FM 100-5 is key to the DRS. While several organizational alternatives are possible to validate FM 100-5 in the field, the study group did not tinker with divisional organizations with tuning adjustments. FM 100-5 is a prescription for change to which the study group made as bold an adjustment as is tactically sound and realistically attainable.

How drastic is DRS? The conscious use of the word restructure rather than reorganization is key. Retained is the concept of the division base, with combat service support tailored to support the three birgades. Also retained are the five levels of command with a major general commanding the division, colonels commanding brigades, lieutenant colonels commanding battalions, captains commanding companies, and lieutenants commanding platoons.

ROLES

GENERALS—CONCENTRATE THE FORCES

COLONELS—CONTROL AND DIRECT THE BATTLE

CAPTAINS—FIGHT THE BATTLE

Also retained are the concepts of force tailoring and command post relationships. Rejected alternatives, in the interest of keeping choices manageable, were the combined arms battalion and the fully self-supporting birgade with organic combat support and combat service support (the German concept).

Working from these trends, doctrine, and problem statements in conjunction with the TRADOC centers and schools, we developed a concept to solve as many problems as possible organizationally.

4. Concept

With trends, equipment potential, and current organization problems identified, the Division Restructuring Study proposes a "clear alternative" to the current H-series TOE armored and mechanized division. The clear alternative is not a grouping of preferred concepts which need to be demonstrated in the field. The concepts are by inspection tactically sound but as big a change as can be made in order to produce measures of relative effectiveness, cost, and worth.

Specifically, by function system these concepts are:

The organization of maneuver forces into more, smaller battalions with about the same total strength offers a potential payoff in improved combat efficiency.

The 3 tank platoon - 36 tank battalion is optimum considering technological advances in Armor.

The 104 man rifle company - 9 man rifle squad is the ideal mechanized infantry fighting force when equipped with MICV with TBAT.

Separate TOW companies offer the best medium for employment of this ATGM.

The fourth battery in each DIVARTY Battalion and additional sections in each DS battery offer the most cost effective alternative to increase artillery firepower, a universally acknowledged goal.

A single mortar system, employing the improved 81mm mortar offers improvement in logistics, training with no loss in effectiveness.

An armored resupply capability in maneuver battalions provides for continued support to units in contact.

The brigade consisting of up to 5 DRS battalions assigned to the brigade offers the advantages of teamwork and does not overly stress the tactical control of the commander.

Hardened TAC CP in M577 or M113 enhance survivability on a battlefield subjected to intense threat artillery attack.

Fire Support Teams (FIST) in armored vehicles with designators offer improved support to maneuver forces and the ability to capitalize on the fire support available: artillery, attack helicopters and tactical air.

The consolidated Aviation Battalion with the Air Cavalry Troop and an Attack Helicopter Company represents the best command, control, and support organization for aviation assets and a base for attachment of aviation elements from Corps or other units.

The DIVADA concept offers an improved solution for providing balanced air defense coverage for the division as well as interfacing with supporting DA HAWK battalions.

The reorientation forward of the division engineers better supports the increased mobility-countermobility role.

The expansion of the CABL concept further frees the company commander to concentrate on his primary mission.

Incorporation of an EW and a chemical defense capability recognizes the realities of modern warfare and responds to threat capabilities.

Weapons system oriented logistics and the fix forward maintenance concept improve operational readiness rates and reduce turnaround time for combat systems.

The Division Ammunition Transfer Capability supports anticipated high ammunition rates and reduces supply lines and turnaround times for maneuver and artillery battalions.

The conversion of transport to higher capability increases the lift potential of the division required in light of the intensity of modern warfare.

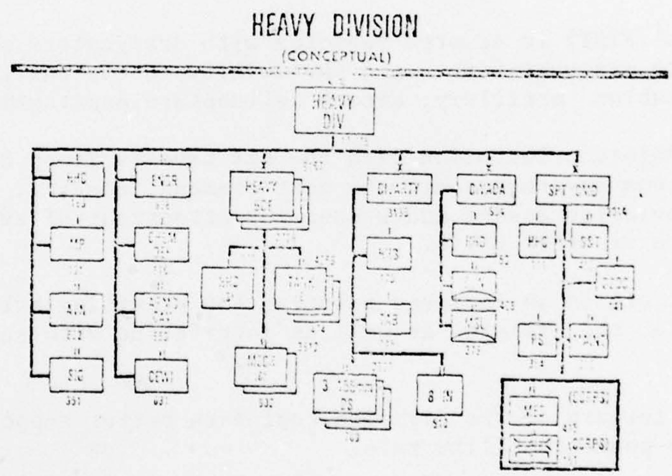
The Corps Medical Evaluation Battalion provides an acceptable solution to processing casualties on a highly mobile armored battlefield.

The increase in officer leaders per major weapons system recognizes the complex, highly technical nature of combat in a capital intensive organization.

The increase of command and control in maneuver units brought about by shortened span of control and more communications enhances battlefield initiative and responsiveness to rapidly changing conditions.

5. Organization.

This slide shows the organization of the conceptual heavy division, which encompasses our current armored and mechanized division.

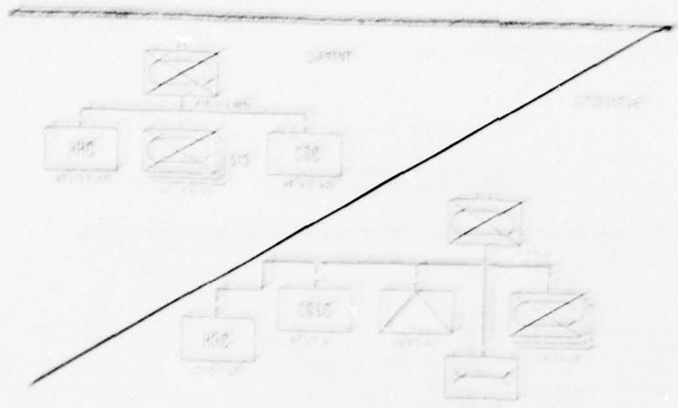


In the interest of space, what follows is a description of the infantry, tank, and artillery organizations. These units are the focus for the first phase of the tests of DRS. For information on the battalion and brigade size organizations, the Division Restructuring Study (1 March 1977) is available on request.

The smaller mech infantry battalion is organized around the same number of combat systems (eventually the IFV) as the current battalion (41)). The

smaller company and platoon is proposed by reducing the squad from eleven to nine men with a base of fire provided by the carrier weapons systems.

MECH INF BN

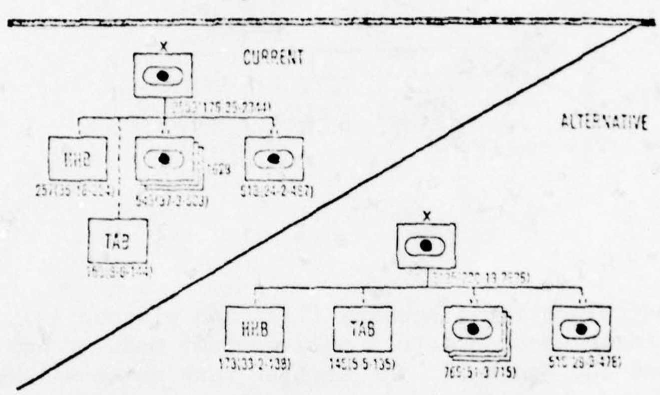


The smaller tank battalion (36), company (11), and platoon (3), is proposed to group these weapons into a pure company mode of employment with tighter command and control. The smaller tank units will be more agile, responsive, and should generate a greater percentage of available combat power. The six H-series TOE tank battalions (54) restructure into nine conceptual battalions (36).

TANK BATTALION

The restructured division artillery will result in improved target acquisition, more responsive, accurate and flexible fire support, increased weapons densities and improved survivability. DIVARTY will be organized with a Target Acquisition Battery, three Direct Support Battalions and one General Support Battalion. The Target Acquisition Battery (TAB) is focused primarily against enemy indirect fire systems. The DIVARTY TOC is the focal point for centralized management of the artillery organic to the division and corps artillery units attached to or reinforcing the division artillery.

DIVISION ARTILLERY



Direct support battalions in each brigade will have four firing batteries, each consisting of eight firing sections, a fire direction element and a small headquarters. This increased density of firing units and fire direction nets will facilitate multiple, simultaneous engagement of diverse targets. Batteries will continue to respond to call for fire from supported maneuver units. The DIVARTY General Support Battalion will consist of four firing batteries, each consisting of four firing sections, and FDC element, and a headquarters. These units will be used primarily for counterfire and air defense suppression missions. When required, their fires will be used to augment the fires of the Direct Support battalions supporting the brigades.

The restructured DIVARTY also incorporates the FIST concept. Each DS battalion will provide brigade, maneuver battalion and company fire support teams from its organic HHB. The FIST team which supports the divisional Armored Cavalry Squadron, is located in HHB of the GS battalion. For test purposes, only enough company FIST teams will be structured to support those maneuver battalions restructured for test.

6. Preliminary Analysis

Organizational change is inevitable as new weapons systems enter the inventory. The Division Restructuring Study provides a vehicle to manage the change.

Test and analysis indicates that the individual organizations developed during the Pilot Study, with some exceptions, show sufficient merit to advance to further testing.

The consensus of the senior Army officers briefed on the study proposals is that the time is right for change and the changes proposed offer promise of substantially improving the Army division. The National Guard favors the changes.

The 1st Cavalry Division at Fort Hood, Texas was selected by FORSCOM as the most favored unit to serve as the test unit. On 22 September 1977, the Chief of Staff approved a Division (-) test as the follow-on phase to this Fall's battalion testing.

If fully implemented throughout the force structure, the combat power of the Army's heavy division and brigades could be increased by 12 MECH INF Bn, 27 Tank Bns, and 520 artillery tubes plus other improvements at a net cost of approximately 10,000 spaces.

On the basis of 10 year investment and operating costs, the relative cost of the proposed division versus the current division is approximately 1.16.

The full effectiveness of the division has not yet been captured. It ranges from very high (1.8) where small unit improvements have been measured to moderately high where the value of small unit improvements and new units have not been adequately measured. In comparison with the current armored division, the restructured division is more effective and worth the cost of conversion. The results of the evaluations conducted from August - December 1976 were:

o High Resolution War Game	1.7
o 3 x 5 Tank Test	1.8
o Firepower Comparison (WEI/WUV)	1.5
o Number of Major Weapons Systems	1.3
o Division Level War Game	1.3

Specifically by area of investigation we determined:

Area of Investigation	Method	Outcome
3 vs 5 Tank Platoon (Ft Hood, Sep 76)	Test	3 Tank Platoon Apparently More Effective.
6 vs 8 Gun Battery	Analysis	8 Gun Battery More Survivable. Most Cost Effective. Alternative to Increase Firepower.
Consolidation of Stinger	Analysis	More Effective. Provides more balanced coverage.
Maneuver Bns	Manual War Game	More Effective. High Payoff in Separate TOW Company.
Division	Computer Assisted War Game	More Effective. Better Kill Ratio. Less FEBA Movement
Logistics		
o Maintenance	Analysis	Greater Returns by 14 percent.
o Ammunition Transfer Points	Analysis	Capability to Meet High Usage Requirement. Reduced Turnaround Time.
o Upgrade of Transportation	Analysis	Higher capacity Worth Cost.
o CH 47 in Division	Analysis	Not Cost Effective.

7. The Test.

The overall evaluation objectives for the Restructured Heavy Division are as follows:

-- To determine the effectiveness of the clear alternative division as compared to the current armored division.

-- To determine if the interface of the clear alternative division's systems and the related echelons above division statements is effective.

-- To determine if the clear alternative division organization lends itself to more efficient and effective training.

There are many ways to evaluate or look at the operation of a division in order to accomplish the overall evaluation objectives. The FM 71-100, Brigade and DIvision Operations, outlines a systems approach to operations--a way to consider the division as a set of interacting and mutually supporting functional systems. This method can bring order to understanding the required interfaces which occur on the modern mobile battlefield. Increasingly, the effectiveness of our combat organization depends upon the proper employment and interaction of complex weapons and equipment, the training of operators and crews, and supporting maintenance and

supply operations. More and more, these modern weapons and equipment operate in the context of functional systems and interface with other complex equipment with which there is a great interdependence. A system is defined as the aggregate of men, equipment, materiel, and procedures organized as an entity to perform a specified function. By using this systems approach as a basis for evaluation, the commanders, staff officers, and evaluators will be able to --

-- Evaluate each system of a given organization as a discrete entity.

-- Evaluate the interaction or interface between systems within or between units.

-- Evaluate the adequacy of training and training developments supportive of a specific system.

In the division there are nine major functional systems, each with a variety of subelements and subsystems. We will address these nine major functional systems plus training and echelons above division. The eleven systems addressed in the evaluation are as follows:

-- Command, control and communications (C^3) system.

-- Maneuver system.

-- Field artillery system.

-- Engineer system.

-- Combat service support system.

-- Air defense system.

-- Electronic warfare system.

-- Intelligence system.

-- Air-ground operations system.

-- Training.

-- Echelons above division.

The total evaluation effort has been organized into four separate but interactive phases to facilitate the planning and execution of the evaluation process, to allow for incremental changes to concepts/organizations, and to provide rationale for designated decision points. The four evaluation phases are the developmental phase, the battalion phase, the division (-) phase, and the analysis phase.

-- Developmental Phase (February 1977 - April 1979). This phase consists of several discrete but complementary activities including detailed evaluation and revision, as necessary, of the Restructured Division

Operations Manuals (RDOMs) and restructured unit ARTEPs and Tables of Organization and Equipment (TOEs); restructuring and training of selected units; and development and evaluation of appropriate tactical and maintenance standing operating procedures (SOPs) by tested units.

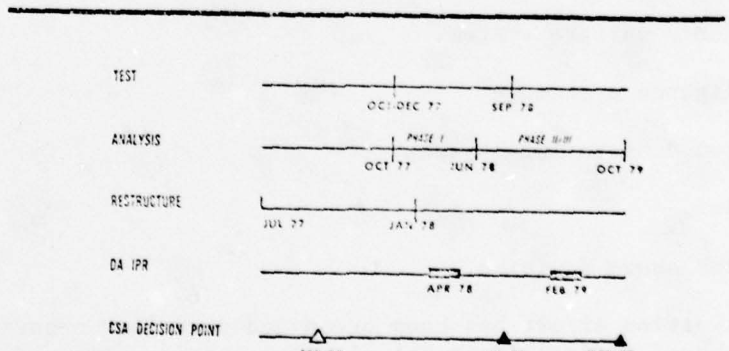
-- Battalion Phase (1 May 1977 - 1 June 1978). This phase will consist of selected instrumented field exercises, operational evaluation of critical issues such as scout section employment and fire support coordination, separate field artillery battery tests, as well as execution of the battalion test for restructured and baseline battalions. Four each H-series and restructured battalions, of which two each are mech and armor, will be tested by 16 December 1977.

-- Division (-) Phase (1 January 1978 - October 1979). This phase will consist of executing the division (-) test, analysis of results and preparation of reports. The division (-) test will focus on C^3 and the internal division combat and combat support organization and functions. It will consist of a two week, two-sided tactical exercise with two restructured brigades in field maneuvers, and a CPX with the remaining brigade supported in each case by the division (-) and selected corps units.

-- Analysis Phase (April 1977 - September 1979). This phase will complement the other three phases. It will provide the analytical support needed to evaluate those aspects of the restructured division which cannot be adequately addressed within the resource constraints of the test program.

On 22 September 1977, the Chief of Staff approved the following test and analysis time line for the DRS program.

TEST AND ANALYSIS TIME LINE



8. Conclusion

The DRS test harnesses the vision for the Army of the 1980's. With a division dedicated to predicting the future organizational design, the Army has an opportunity to manage change in a meaningful, realistic way.

STATIC ANALYSIS - AN ANSWER TO THE COMPLEXITY CRISIS

MR. NORIG G. ASBED
MR. L. STANDLEE STEENROD

US ARMY CONCEPTS ANALYSIS AGENCY

1. Apparently since Mr. Hardison's keynote address at the XV AORS, people are beginning to take the complexity crisis to heart and letting simplicity slip in where so called sophistication previously reigned. I am reporting on one such example; a study where a simple, easily understood methodology was used to address a major Army question. While taking credit for the simplicity of the methodology, this must be tempered by the immediately evident fact that we used a complex simulation in the study as well. Actually, we used the two models in parallel for comparative results.

2. Let me depart from generalties and describe specifically the study and then the methodology. The study was the Army Requirements for Close Air Support (RCAS). The title clearly describes the objective of the study. The setting was in NATO's Central Region and three US ground forces were to be considered. Many of you, I am sure, are familiar with similar studies in the past. As a study, apart from scenario specifics, the approach was pretty straight forward: Drag out the favored complex theater-level combat simulation model; insure air is appropriately considered; game the alternatives; publish the results. Right? Yes; for the most part: But someone suggested that a simple formulation could do the job as well. Heeding the advise, facts were obtained on a "static analysis", developed by Dr. Payne, and used by NATO's Research Study Groups 1 and 6 to investigate force requirements to blunt a Warsaw Pact breakthrough. When confronted with a simple, sound approach to our study, and with Mr. Hardison's speech ringing in our ears, what else could we do but use it. However, we weren't completely free from the pull of the sophisticated approach, read "complex model," and therefore the theater simulation model, IDAGAM-I, was used in parallel.

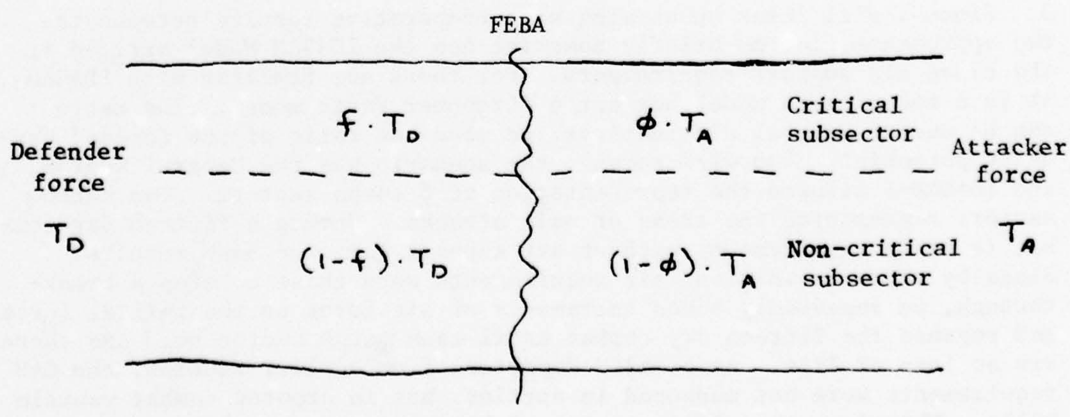
3. Since I will later be showing some comparative results between the two approaches, let me briefly describe how the IDAGAM Model arrived at the close air support requirements. For those not familiar with IDAGAM, it is a force ratio model but not a firepower ratio model. The ratio can be one of several alternatives, we used the ratio of the forces' casualty potential. You will recall, the scenario was the Central Region, and IDAGAM-I allowed the representation of 8 corps sectors. Two narrow sectors represented the areas of main attacks. Gaming a fifteen day combat (a study requirement) without air support gave the base results. Since by study definition, air requirements were those to stop a breakthrough, we repeatedly added increments of air force to the initial forces and regamed the fifteen day combat until each corps sector held and there was no loss of FEBA. As a major departure from earlier studies, the CAS requirements were not measured in sorties, but in armored combat vehicle kills. Therefore the model results of kills of armored combat vehicles

by tactical air in this "no FEBA lost" case became the requirements for close air support.

4. Undoubtedly you now want to deluge me with questions about missions, priorities, attrition levels, etc. Let me side step those questions in favor of discussing the simple methodology which of course had none of those factors anyway.

5. The "Static Analysis Model" is based on the philosophies of massing of force and economy of force. If we consider a single sector, essentially a corps front, the attacker wants to mass his force on a narrow front, achieving a sufficiently large force ratio in this narrow, critical subsector to result in a breakthrough. Throughout the rest of the sector, which the attacker may term "non-critical," he will economize his forces, deploying only sufficent forces to hold the defender. While the attacker is massing, it is assumed that the defender's forces, including reserves, are initially uniformly distributed across the sector. The defender soon recognizes the massing in the critical subsector and deploys his tank reserves to this area.

6. Now while you have a mental picture, let me define some terminology. For the basic model there are only four parameters to remember; two represent the total sector forces (attacker and defender); one represents the critical subsector width; and one represents the fraction of the attacker's force being massed. If we consider the sector to be any fixed width, the width of the critical subsector can then be represented by a fraction, f , of the sector width. If the defender's forces (including reserves) in the sector are represented by T_D then initially the defender will have $f \cdot T_D$ forces in the critical subsector, and $(1-f) \cdot T_D$ in the non-critical subsector. The attacker estimates f and will select his total sector force T_A , and the fraction to mass, ϕ , so that the desired holding force ratio is achieved in the non-critical subsector, and the breakthrough force ratio is acheived or exceeded in the critical subsector. If $\phi \cdot T_A$ of attacker's forces are in the critical subsector, then $(1-\phi) \cdot T_A$ would be the forces in the non-critical subsector. The initial force configuration is thus:



f : Fraction width of the critical subsector

T_D, T_A : Defender's and attacker's total sector forces, respectively.

ϕ : Fraction of attacker's force massed in critical subsector.

To this point, I have not described how forces are measured. The attacker's forces were measured by the number of tanks and armored personnel carriers; collectively to be called armored combat vehicles. The defender's forces were measured by the number of anti-tank weapons systems (tank's and anti-tank weapons). It was assumed that all weapons are weighted equally.

The force ratio in the critical and non-critical subsectors are:

$$R_{\text{critical}} = \frac{\phi \cdot T_A}{f \cdot T_D}$$

$$R_{\text{non-critical}} = \frac{(1-\phi) \cdot T_A}{(1-f) \cdot T_D}$$

Notice that if the sector forces T_A and T_D are determined, and the attacker selects f and the holding force ratio $R_{\text{non-critical}}$, then ϕ is determined.

7. We assumed that the defender had forces in reserve in the sector, say fraction K. The reserves (like the forces forward) were uniformly distributed in the sector, therefore the reserves in the non-critical subsector are $K \cdot (1-f) \cdot T_D$ and could be redeployed. If we assume only tank components of the reserves will be redeployed, name them T_D', then $K \cdot (1-f) \cdot T_D'$ forces would be redeployed from the non-critical subsector the the critical subsector. The force ratio in the critical sector would become:

$$R_{\text{critical}} = \frac{\phi \cdot T_A}{f \cdot T_D + K \cdot (1-f) \cdot T_D'}$$

8. Having defined the force ratios, requirements for close air support are based on lowering the ratio in the critical subsector to a value which would prevent breakthrough. Since the attacker is assumed to be deploying only a holding force in the non-critical subsector, there would be no requirement for close air support in that subsector. If the defender estimates a threshold force ratio in the critical subsector to prevent the breakthrough as $R_{\text{critical, threshold}}$, then the requirement for close air support to reduce the attacker force can be calculated from the equation:

$$R_{\text{critical, threshold}} = \frac{\phi \cdot T_A - \Delta_{CAS}}{f \cdot T_D + k \cdot (1-f) \cdot T_D'}$$

The final equation of the static model thus determines the close air support requirements to prevent a breakthrough in terms of armored combat vehicle kills.

9. The static analysis portion of the RCAS study was to address a conflict of fifteen days duration composed of two intense battles with an intervening lull period. While application of the static model could have been repeated for the second battle after assuming loss factors and loss exchange ratios, certain difficulties arise in determining the battle's end. It was therefore decided to extend the formulation and account directly for these loss factors.

10. In order for the defender to prevent the breakthrough, the threshold force ratio in the critical subsector must be true at the end of the intense battle. Beginning with our previous equation, if we assume that the defenders' losses will be a fractional loss ρ, and the loss exchange ratio (attacker/defender) is e, the surviving forces and their force ratio at the battle's end becomes;

$$R_{\text{critical, threshold}} = \frac{\phi \cdot T_A - \Delta_{CAS} - e \cdot \rho \cdot \left[f \cdot T_D + k \cdot (1-f) \cdot T_D'\right]}{(1-\rho)\left[f \cdot T_D + k \cdot (1-f) \cdot T_D'\right]}$$

11. As you see, complexity is beginning to creep into the formulation. Even so, two additional factors were explicitly treated; preparatory artillery firing against anti-tank weapons; and defender's attack helicopters. If E is the fraction of anti-tank weapons lost to preparatory artillery, and S_{AH} is the attacker's losses to attack helicopters, the force ratio appears finally as:

$$R_{\text{critical, threshold}} = \frac{\phi \cdot T_A - \Delta_{CAS} - e \cdot \rho \cdot [\quad] - S_{AH}}{(1-\rho) \cdot [\quad]}$$

where, $[\quad] = f \cdot T_D + k \cdot (1-f) \cdot T_D' - E \cdot f \cdot (T_D - T_D')$

which is the defender's force in the critical subsector at battle initiation.

and, $(T_D - T_D')$ are the anti-tank weapons of the defender's force.

12. Supporting equations are necessary to determine the attack helicopters kill contribution. They are:

$$\begin{pmatrix}\text{helicopter ACV}\\ \text{kills per day}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{helicopters}\end{pmatrix} \cdot \begin{pmatrix}\text{availability}\end{pmatrix} \cdot \begin{pmatrix}\text{sorties}\\ \text{per day}\end{pmatrix} \cdot \begin{pmatrix}\text{ACV kills}\\ \text{per sortie}\end{pmatrix}$$

and,

$$\begin{pmatrix}\text{helicopter}\\ \text{losses per day}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{helicopters}\end{pmatrix} \cdot \begin{pmatrix}\text{availability}\end{pmatrix} \begin{pmatrix}\text{sorties}\\ \text{per day}\end{pmatrix} \cdot \begin{pmatrix}\text{helicopter}\\ \text{losses per day}\end{pmatrix}$$

This set of extended equations is known as the Quasi-Dynamic Model. I might note at this point that this equation can be programed on a hand calculator in a very few steps.

13. Applying the Quasi-Dynamic Model to the study scenario, required the selection of values for the parameters. Also, to amass the close air support requirement across the Central Region, each sector was treated separately and the ACV kill requirements summed. The force totals in each sector are essentially set by the scenario years, 1977 and 1982, and the warning times. The value selection for the remaining parameters was the subject of much discussion. To some degree, we benefited from prior discussions within the NATO Research Study Groups. After examining some suggested values and conducting some sensitivity analysis, the following values were selected.

f = selected such that the width of the critical subsector was 15 kms.

$R_{\text{non-critical}}$ = 1.5; force ratio in non-critical subsector.

K = .25; fraction of defender's forces in reserve.

$R_{\text{critical, threshold}}$ = 4; force ratio to prevent breakthrough.

E = .1 and .3; fraction of defender anti-tank weapon losses to preparatory fire for first and second battles respectively.

P = .25; fraction of defender's force lost.

e = 2; exchange ratio (attacker/defender).

These values were all selected before comparison with the IDAGAM results. Remaining assumptions for application of the methodology were:

a. The two intense battles would be three days in length.

b. In the non-critical subsector, as well as in the period between the two battles, it was assumed that the attacker accepts 10 percent loss of his forces equally inflicted by the defender's ground forces and close air support.

c. Attack helicopter performance was assumed to duplicate the COEA for the AH-1S helicopter with extended range TOW.

14. Having previously described the IDAGAM-I approach to the study, let me use IDAGAM's close air support requirements for the three force configurations as a base and show the close air support requirements from the Quasi-Dynamic Model as a percentage. The requirements are as follows:

Force Configuration	Quasi-Dynamic CAS Requirement (Percent of IDAGAM Requirement)
1	99
2	93
3	115

While there are a few qualifiers, I could add to temper these close results, Mr. Hardison's sixth prerequisit in his AORS XV talk already challenged me to accept the usual finding that the results from the simple model and the complex model will be close.

15. In closing, I can say that the RCAS Study has become very popular. Is it popular because of the stated CAS requirement; or is it popular because the methodology, at least the Quasi-Dynamic portion, is simple and understandable? Looking ahead to the 80's, I expect simple models to reappear in Army studies. The Quasi-Dynamic methodology will likely be appearing in other CAA studies; that is if we can fight off those who want to make it more comprehensive, sophisticated and complex!

A Static Model of Combat Between Air Forces

S. J. Deitchman*

The model that follows applies to the air battle the same principle of concentration that was used for the ground situation in the main paper. The purpose of this model is to show the instantaneous force ratio between Red and Blue (attacking/defending) aircraft over Blue-defended areas where Red is making a main attack effort, as a function of various situational and tactical variables. Red and Blue start with their forces in some overall ratio, R. Red's objective is to maximize his local force ratio over critical areas by concentrating his attack in time and space as much as he can, while performing other necessary and diversionary attacks. Blue's objective is to minimize Red's force ratio advantage over the critical areas by appropriate force utilization and tactics, while not perfectly knowledgeable of Red's plans.

If some total number of aircraft in a force must be assigned uniformly to individual protected areas or sectors, then the number of aircraft assigned to each sector is $\frac{\text{total number}}{\text{number of sectors}}$. If all the aircraft could fly all day then this ratio would describe the number of aircraft in the air over each sector at any time. However, if flying time is restricted, then the number of aircraft in the air at any time, uniformly distributed over time, must also be related to the fraction of the time that the aircraft can fly. Then, the basic relationship on which this model is based is that the number of aircraft, n, out of a uniformly distributed aircraft force, F, that exist at any time over some area or sector is given by:

$$n = \frac{F\, s_d h}{A \cdot d} \qquad (1)$$

where s_d is sorties per day (per aircraft), h is hours per sortie (per aircraft), A is the number of sectors over which the aircraft can appear, and d is the number of hours per day during which the n aircraft are over the particular area under consideration. The units of n are aircraft per area or sector protected. The equation really describes a CAP situation (i.e., h is time over the area). For small distance to travel by high-speed aircraft, such as might be typical of fairly small sectors over the Central front in Western Europe, the technicality can be neglected. For other situations, however, such as defense of the Continental United States or European operations where defense aircraft fly from distant bases, the difference is important because h will be considerably less than total sortie time. Thus Eq. (1) implicitly involves the key aircraft parameters of range, speed, and endurance.

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Let Red be the attacker and have an aircraft force, F_R, of which he wants to reserve kF_R for use at times or for purposes other than his main (concentrated) attacks;* and let Blue be the defender and have a force, F_B of which he wants to reserve mF_B to throw against the main Red attack. He will have $(1-m)\ F_B$ aircraft to use in generalized or distributed defense. Some of this fraction of the force will appear above the sectors of main Red attack and some will appear (or be held ready to appear) over the other sectors where Blue chooses to defend because Red may attack. Let Blue also have a force, ΔF_B, that he can add to his defense from outside the battle area.** Red has no awareness that ΔF_B will be used for air defense (perhaps because the decision will be ad hoc).

Red is, however, assumed to be aware of A, F_B, and m,† and desires to maintain some balancing force ratio, r, in diversionary and supporting attacks against sectors outside those of his main attack, while the main attack is under way. The number of aircraft he has available for his concentrated effort is therefore $(1-k)\ F_R$, less the number of aircraft he must use to maintain r. If he will concentrate his main attack over some fraction of the defended sectors, f_A, then the aircraft he has available for his main attack are

$$(1-k)\ F_R - r\ (1-m)\ (1-f_A).$$

Red will also concentrate his main attack into some fraction, f_T, of a 24 hour day. Then the number of Red aircraft over each sector of main attack (or critical area) is, from (1),

$$n_{cR} = \frac{[(1-k)\ F_R - r\ (1-m)\ (1-f_A)]\ (s_d h)_R}{(f_A \cdot A)\ (f_T \cdot 24)} \qquad (2)$$

The number of Blue aircraft that can appear over each critical area is made up of: the number from the fraction of the force, $(1-m)\ F_B$, that would "normally" appear or be held ready to appear there, remembering that the $(1-m)\ F_B$ aircraft are uniformly distributed

*E.g., attack at other times than those of the main effort, or attacks on other fronts so that the aircraft are unavailable for the main attack.

**This could be, e.g., part or all of an air-defense-capable force that had been assigned to ground attack missions.

†We grant him this intelligence advantage because he is the attacker and has "infinite" time to prepare.

over all protected areas and times given by d in Eq. (1); the number from the fraction of the force, mF_B, that can appear over each critical area at the critical time; and the number from ΔF_B that can similarly appear. Then, again from (1),

$$n_{c_B} = \frac{(1-m)\, F_B\, (s_d h)_B}{A \cdot 24} + \frac{m\, F_B\, (s_d h)_B}{(f_A \cdot A)\,(f_T \cdot 24)} + \frac{\Delta F_B\, (s_d h)_B}{(f_A \cdot A)\,(f_T \cdot 24)} \qquad (3)$$

If we let $\frac{(s_d h)_B}{(s_d h)_R} = \beta$ (the relative times in the air of aircraft from the opposing forces), and let the overall, initial force ratio be $R = F_R/F_B$, then the local (Red/Blue) force ratio over the critical areas (sectors where Red concentrates his attack) is

$$\frac{n_{c_R}}{n_{c_B}} = \phi = \frac{1}{\beta} \cdot \frac{[(1-k)\,R - r\,(1-m)\,(1-f_A)]}{[(1-m)\,f_A\,f_T + m] + \frac{\Delta F_B}{F_B}} \qquad (4)$$

or, for convenience,

$$\phi = \frac{1}{\beta}\ \frac{\delta}{\alpha + \frac{\Delta F_B}{F_B}} \qquad (5)$$

If Blue wants to achieve some local, critical force ratio, ϕ', after he has started with a force, F_B, by adding ΔF_B, then

$$\Delta F_B = \frac{F_B}{\phi' \beta}\ \delta - F_B \alpha \qquad (6)$$

where δ and α are defined in Eq. (5). The number of Blue aircraft drawn from F_B that are instantaneously over any Red sector of concentration are

$$n_{c_{B0}} = \frac{F_B\,(s_d h)_B}{A \cdot 24}\ \left[(1-m) + \frac{m}{f_A\, f_T}\right] \qquad (7)$$

The number of augmentation aircraft contributed by ΔF_B must still be distributed over the sectors and times of main Red attack, giving

$$\Delta n_{cB} = \frac{\Delta F_B \ (s_d h)_B}{(f_A \cdot A)\ (f_T \cdot 24)} \tag{8}$$

additional aircraft over each sector.

The model is useful for first-order assessments of trends as force sizes, force characteristics, tactics, and strategies in an air war are changed. Its utility can be illustrated by an example of the kinds of results it gives. Assume the following parameters to remain fixed: $k = .25$; $r = 1$; $f_T = .1$ (i.e., Red reserves 25% of his force for other purposes than his main effort; tries to maintain a force ratio of 1 by drawing on his main-effort force for diversionary attacks in areas outside those of his main effort; and concentrates his main effort into a time period of about $2\frac{1}{2}$ hrs). The parameters A, f_A, F_R and F_B are variable, by scenario and strategy or tactics. Values of F_B are 150, 250, 400. $s_{dR,B} = 2.5$ and $h_{R,B} = 1$ are reasonable for modern combat aircraft, although they vary with scenario. The number of aircraft Blue reserves to meet the main Red effort, m, is a primary tactical variable. It can be treated two ways: a fixed number of aircraft can be used for distributed defense,* with the remainder of the defending force (however large it may be) held in reserve to meet the main attacks; or a fixed fraction of any defending force can be held in reserve for the purpose. In the first case, values of $m_0 = .25, .5, .75$ are associated with $F_B = 150$; the number of aircraft used in distributed defense is thus determined and held constant as F_B varies, allowing m to seek its own value based on F_B. In the second case, values of m = .25, .5, .75 are held constant for any size force, F_B.

Table 1 lists the parameters of four scenarios, associated with defense of a postulated Blue force deployment:

*E.g., in CAP over the defended areas, or on strip alert to defend when Red approaches those areas, only.

TABLE 1. Sample Scenarios

Scenario No.	Defended Sectors	Blue Strategy (Sectors Defended by Aircraft)	Red Attack Force	Red Strategy (Concentration of Main Attack)	Relative (Blue/Red) Time Over Target Areas
1	4 forward corps + rear area $A = 5$, $f_A = .4$	Defend all sectors	800	Attack 2 forward corps, only	$\beta = 1$
2	As above; $A = 5$ $f_A = .4$	Defend all sectors	1100	Attack 1 forward corps + rear area	$\beta = 1$
3	$A = 3$ $f_A = .67$	Defend where attacked, plus 1 other sector	700	Same as Scenario 2, except, fighters withheld for air defense of Red area	$\beta = 1$
4	$A = 3$ $f_A = .67$	Same as Scenario 3, except fly from bases farther to the rear	1100	Same as Scenario 2	$\beta = .67$ (Reduced Blue time over protected sectors)

Figure 1 shows the effects of changes in some of the primary variables on force ratio over the main battle sectors (critical areas), for the different scenarios. The patterns are the same in all the scenarios, but the levels of ϕ differ as numbers of Blue and Red aircraft, and other variables, change. It is clear from the figure that the closer Blue approaches to using all his aircraft for distributed defense ($m \rightarrow 0$), the easier it is for Red to increase his force ratio advantage over the critical areas by concentrating his efforts. Conversely, if Blue can learn where Red is concentrating (despite the "noise" of the diversionary attacks) with enough confidence to reserve most of his force to meet the main Red attack ($m \rightarrow 1$), then he can, by concentrating his defense, essentially prevent Red from achieving a better force ratio than the initial force ratio, R, despite Red's concentration. (Red has,

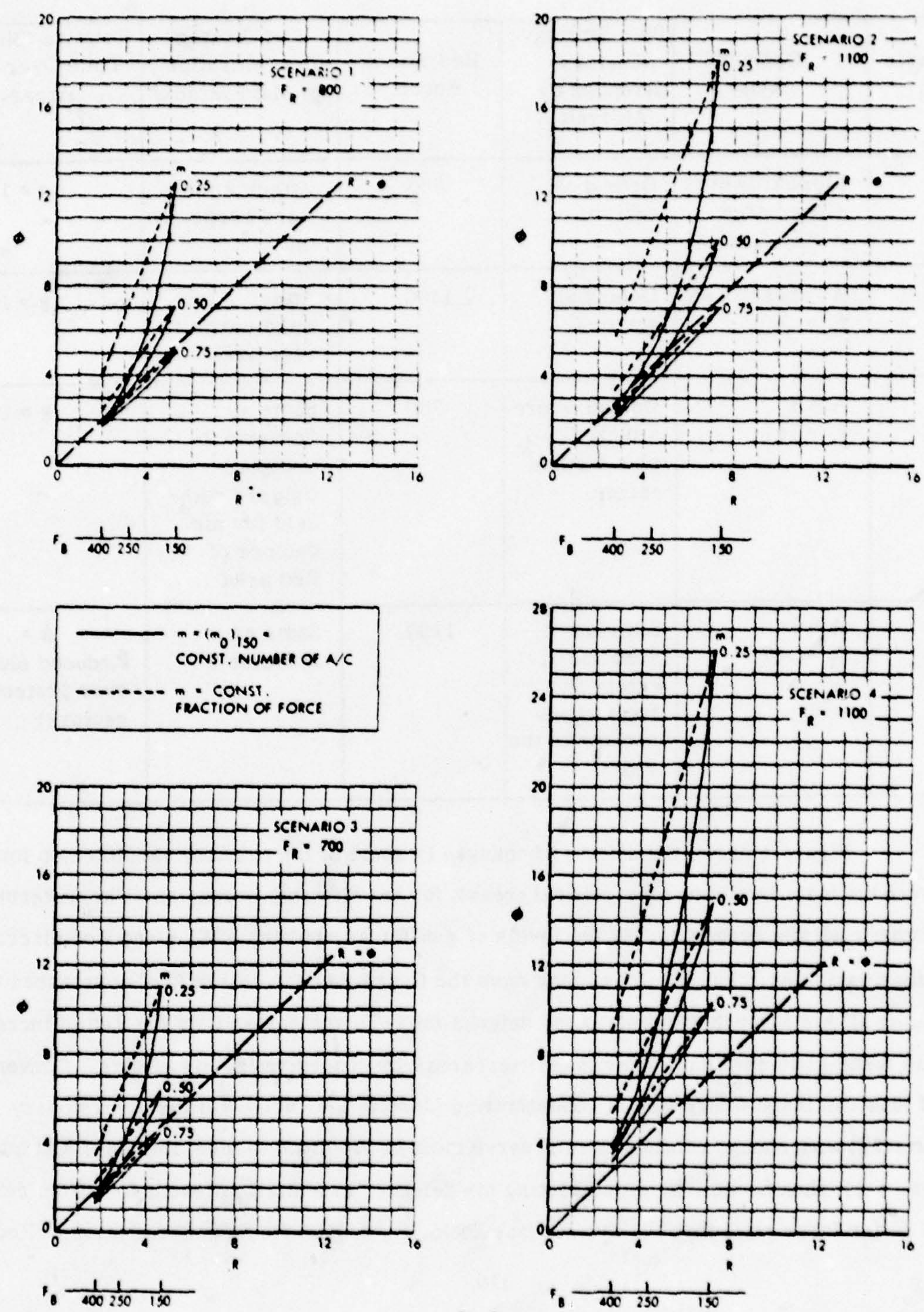
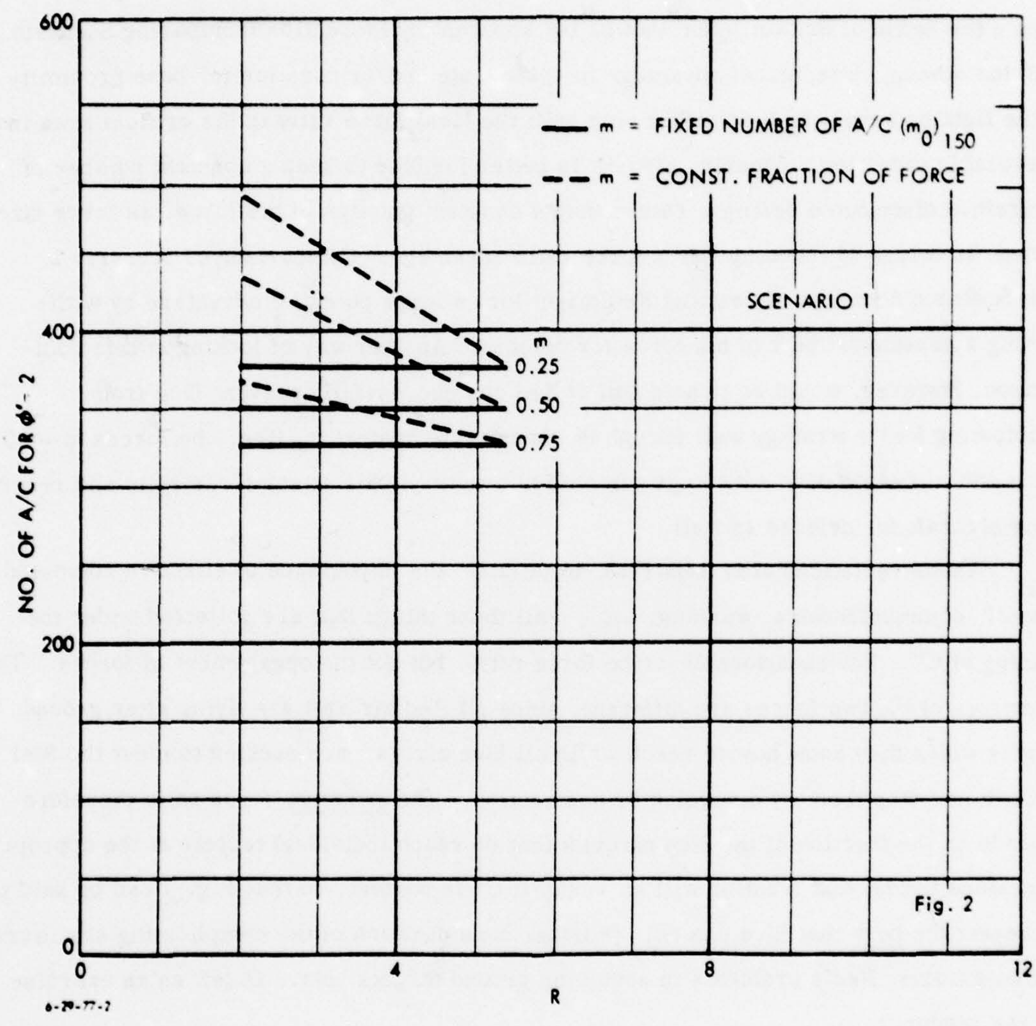

SCENARIO 1
F_R = 800
SCENARIO 2
F_R = 1100
SCENARIO 3
F_R = 700
SCENARIO 4
F_R = 1100
m
0.25
0.50
0.75
R = ∞
Φ
R
F_B
400 250 150
m = $(m_0)_{150}$ = CONST. NUMBER OF A/C
m = CONST. FRACTION OF FORCE

Fig. 1

of course, other options not examined here, via k and r.) This perhaps illustrates quantitatively the value of intelligence, and is in fact reminiscent of the RAF operations during the Battle of Britain. Not shown, but apparent by inspection (comparing Scenario 4 with the others), a technical advantage in sortie rate and/or duration (or base proximity to the fighting area) can help either side shift the local force ratio in the critical area in a favorable direction. Clearly, also, it is better for Blue to keep a constant number of aircraft in distributed defense, rather than a constant fraction of his force, as force size varies, in terms of reducing Red's force ratio advantage. Comparison of Scenario 2 with Scenario 3 results shows that Red might lose a large potential advantage by withholding a substantial part of his force for defense. Another way of looking at this comparison, however, would be to note that if Red can successfully prevent Blue from anticipating Red's strategy well enough to concentrate against it, (i.e., he forces $m \rightarrow 0$), Red's initial quantitative advantage can help him multiply his attack force ratio and reserve some aircraft for defense as well.

These variations also illustrate, implicitly, the importance of effective command, control, communications, warning, etc., --all those things that are collected under the heading of C^3. The equations describe force ratio, but not the engagement of forces. The objectives of the two forces are different, since all Red aircraft are flying after ground targets which they know how to reach while all Blue aircraft are seeking to meet the Red aircraft and stop them by diversion or destruction. The effective force ratio therefore depends on the fraction of the Blue aircraft that do reach individual targets at the appropriate places and times; that fraction will be 1 only if C^3 is perfect, so that Fig. 1 can be said to represent the best that Blue can do. (Further consideration of the complicating significance of Red escorts, Red's problems in acquiring ground targets, etc., is left as an exercise for the reader.)

It is apparent from Fig. 1 that although Blue can operate so as to inhibit Red's concentration from yielding a very large force advantage in a critical area, it is not easy for Blue to overcome an initial force disadvantage, except by improving $(s_4 h)$ or by increasing his numbers (assuming he has solved his intelligence and C^3 problems to good advantage). Figure 2 shows the number of Blue aircraft that would be required to hold Red to a local



m = FIXED NUMBER OF A/C $(m_0)_{150}$
m = CONST. FRACTION OF FORCE
SCENARIO 1
m
0.25
0.50
0.75
NO. OF A/C FOR $\phi' - 2$
600
400
200
0
0
4
8
12
R
6-29-77-2

Fig. 2

force ratio of 2 in the critical area ($\phi' = 2$), as a function of initial force ratio, R, in Scenario 1 ($\phi' = 2$ might be an appropriate goal if, for example, Blue's aircraft were believed good enough to achieve an exchange ratio of 2 against Red). The total number of aircraft required, ($F_B + \Delta F_B$), does not vary strongly with m_o, or at all with R, in the case where a constant number of aircraft is assigned to distributed defense. This is another argument for that strategy--it is less sensitive to initial uncertainty.

Figure 3 shows $(F_B + \Delta F_B)_{\phi' = 2}$ for the various scenarios (ΔF_B might, for example, be drawn from a dual-capable aircraft force that had been assigned attack missions). The most difficult scenario for Blue is No. 4, where Red has a sortie duration advantage. Even here, however, Blue can keep Red from achieving a force ratio > 2, almost regardless of his strategy in reserving forces, with approximately half of Red's force; in the other cases, this can be done with less than half. The entire figure, then, illustrates the assignment flexibility inherent in a multi-purpose air force, when there is great uncertainty about how the battle will develop. (The technical problems for Blue of achieving a 2:1 exchange ratio in the face of a numerical disadvantage of 2:1, under conditions that are probably as close to "Lanchester-squared" as any combat situation would allow, should not be underestimated, although such achievements have not been unknown in recent conflicts.)

Another possibility to achieve the equivalent of $\phi' = 2$ (or any other value) would be to add only part, or none, of ΔF_B as aircraft, but to add the equivalent capability as ground-based Blue defenses. Establishing equivalence between aircraft and ground-based defenses is, of course, a major analytical problem. It might be done, for the airspace over a defended area, in terms of comparable P_K or attrition potential against Red attackers. Thus, the number of SAMs (e.g.) that could shoot down the same number of enemy aircraft as ΔF_B during the time ($s_d h$) might be substituted for ΔF_B and the costs compared. This very restricted view of the air defense force tradeoff would not, however, by itself permit choice of systems or system mixes, since the alternate uses of aircraft and alternate measures such as net damage inflicted or sustained by Blue or Red ground targets are not included in the problem; it would simply be an indicator of where the proportioning of a mix might start.

It is possible, also, to use this model formulation and illustration to characterize some of the intuitively obvious tradeoffs between aircraft and ground-based air defenses. The factor f_A depends in part on the number, out of the total possible, of sectors within

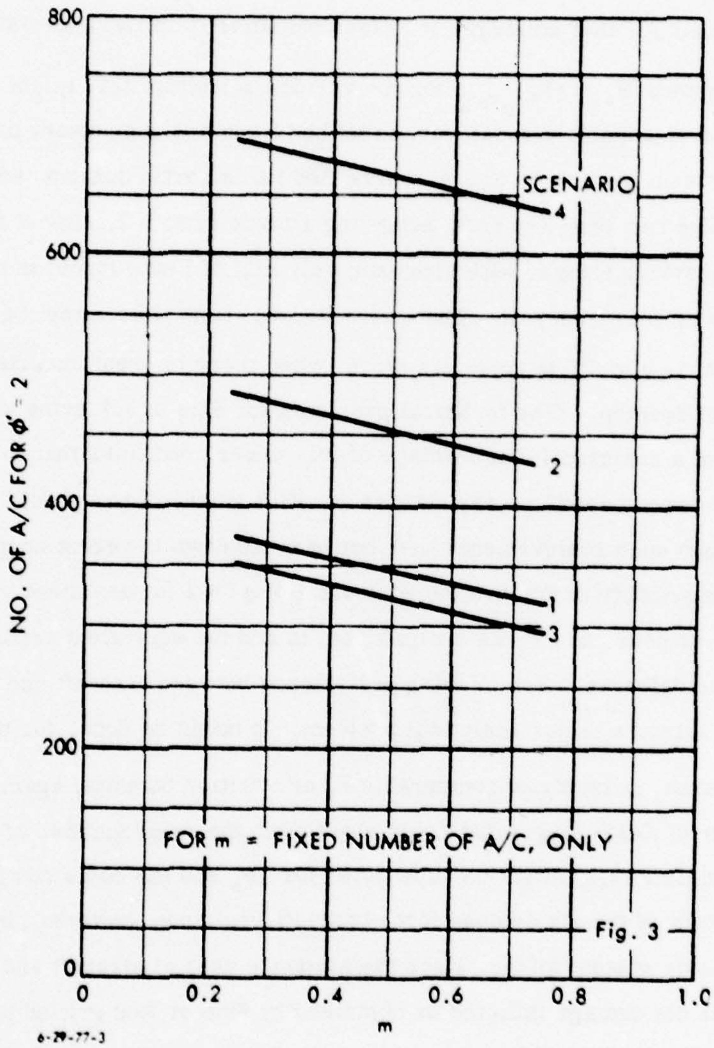

800
600
400
200
0
0
0.2
0.4
0.6
0.8
1.0
m
NO. OF A/C FOR $\phi' = 2$
SCENARIO
4
2
1
3
FOR m = FIXED NUMBER OF A/C, ONLY
6-29-77-3

Fig. 3

Blue's total area that Blue chooses to defend with aircraft. Elsewhere, there are no defending aircraft assigned, so that other defenses, to some level, are needed. This applies also to the possibility that attacks will come at times during which Blue aircraft cannot appear over the areas to be defended, because they are being serviced or are assigned otherwise. These facts, alone, argue for a mix including SAMs, since if Blue were to use only aircraft for defense the only way he could minimize the time and space left uncovered would be to spread his aircraft more uniformly, thus helping Red maximize the force-ratio gains from concentration.

On the other hand, the choice by Blue of F_s, A, and m highlights the flexibility and mobility of the aircraft for defense. For the SAM defenses will be designed (at some level) to meet the main attack. Since SAMs are in ground units or deployed over specified terrain, and their mobility corresponds to that of ground units (or occasional helicopter lift) they can't be shifted fast enough over all A to concentrate against a specific attack; and successive attacks can come in diverse places and at (almost) arbitrary times. Therefore Blue's "off-peak" and "out-of-main-area" ground forces have to carry all the freight of defense systems designed primarily to help protect them if they are subject to a main attack, but clearly excess for other conditions.

The reflections on the force ratio model results and their implications thus illustrate analytically the qualitative advantages and penalties of each arm of the active air defense duo: in the face of arbitrary Red choice for times and places of attack, defense aircraft in a given force are "infinitely" assignable, but not always available when and where they are needed; ground-based defenses fill the gap, but are excess baggage and not easily accessible for use elsewhere when the forces they protect are not under attack. The model, taken in conjunction with other analyses of specific questions, can help "size" the various defense components, at least in rough first approximation to establish the ranges of force size parameters that should be considered in more careful and sophisticated analyses.

ABSTRACT

TITLE: ANALYSIS OF THE PROVISIONING SYSTEM AS APPLIED AT HQ, ARRCOM

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ORGANIZATION: HQ, ARRCOM, DRSAR-SA, Rock Island, IL 61201

ABSTRACT: The provisioning efforts conducted at this Headquarters are experiencing long lead times. This study was undertaken to outline the provisioning system as prescribed in the Commodity Command Standard System (ALPHA), SOP's of the Maintenance and Materiel Management Directorate, and appropriate Army Publications. Once the flow was determined, the system was simulated using GPSS. Critical problem areas were identified and proposed changes in the system evaluated. Sensitivity analyses were performed to determine the overall effect of these changes on a provisioning effort.

ESTIMATED TIME REQUIRED FOR PRESENTATION: 30 Minutes

CATEGORY APPROPRIATE FOR THIS PAPER: Special Session Topic: Logistics

SUBJECT: Analysis of the Provisioning System as Applied at HQ, ARRCOM

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I. BACKGROUND

Provisioning is a management process for determining and acquiring the range and quantity of support items (repair parts, special tools, test equipment, etc.) necessary to operate and maintain weapon system or end item for an initial period of service. The provisioning process consists of a series of critically timed actions extending over a wide range of functions. These functions include design, maintenance planning, requirements determination, item entry control, cataloging, procurement, and contract administration. In order to be effectively accomplished, the provisioning process must be performed as a coordinated military and civilian developer effort.

Planning for provisioning should begin early in the life cycle of a weapon system or end item of military design, or before the procurement of an adopted commercial system. Provisioning planning is performed to insure that appropriate standards and specifications are included in preproduction and production contracts. Early provisioning planning, however, is influenced by design changes that may occur as the weapon system or end item is developed. In addition, design changes to a fielded weapon system or end item must be monitored to insure that the many required provisioning actions are accomplished so that adequate initial support for the modified weapon system or end item is provided.

General principles that apply in performing an initial provisioning effort are:

1. Begin provisioning planning early in the material life cycle. This planning is an essential segment of the integrated logistic support plan (ILSP).

2. Screen manufacturer's part numbers and other reference number data to insure that unnecessary or duplicate items do not enter the wholesale and retail supply systems.

3. Compute initial support requirements utilizing the latest production and delivery schedules and test data (OT/DT). The requirements should take into consideration minimum operating levels and repair or overhaul pipeline quantities in order to insure supply system and support maintenance responsiveness.

4. Maximize the use of existing resources rather than initiate new procurement.

5. Minimize initial investment costs of repair parts by using phased provisioning and other techniques.

6. Allow sufficient time to insure that all provisioning functions (cataloging, assignment of stock numbers, etc.) are accomplished.

Provisioning is generally classified as three basic types: initial, follow-on, and reprovisioning. Initial provisioning is the first-time provisioning of a new weapon system or end item, follow-on provisioning is the subsequent provisioning of the same system by the same contractor, and reprovisioning is the subsequent provisioning of the same system by a different contractor. These basic forms of provisioning can be modified by the use of "phased provisioning". "Phased provisioning" is a concept in which the quantities of selected initial support items are computed, but the procurement of most of these items is deferred until latter stages of development. This deferral permits costs to be spread over several fiscal years; allows for the incorporation of the latest design changes, development of firm operational and maintenance plans, and completion of deployment plans.

II. OBJECTIVE

The objective of this study was to outline the provisioning process, to analyze problem areas and to evaluate proposed changes to the current provisioning process.

III. STUDY APPROACH

The procedures for accomplishing a provisioning action were described in a network (Inclosure 1) by utilizing appropriate CCSS standard operating instructions (CCSSOI), publications, and contributions from personnel within the Maintenance and Materiel Management Directorates. The network was then simulated using the General Purpose Simulation System (GPSS) developed by the Science Research Associates, Incorporated, a subsidiary of IBM.

The time to complete a provisioning process could not be determined from historical data, however, a generalized time estimate was developed by the provisioning, supply, and cataloging personnel of the Maintenance and Materiel Management Directorates. This estimate was used to aid in verifying the simulation results. This study covers the provisioning process from the time that the Provisioning Branch of the Maintenance Directorate receives the provisioning data from a developer until the entire provisioning package is ready for procurement action. This process time plus the administrative leadtime[1] for the acquisition of secondary items indicates total processing time within HQ, ARRCOM.

IV. BASELINE ANALYSIS

The GPSS model was structured to simulate the provisioning process within the Maintenance and Materiel Management Directorates to provide

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[1] R. C. Banash, et al, Secondary Administrative Lead Time Simulation Study, SAO Note 2, Systems Analysis Office, ARMCOM, Rock Island, IL, June 74.

a quantitative estimate of the processing time required for a provisioning effort.

GPSS provides a standard set of statistics for three distinct entities: facilities, storages, and queues. A facility can process only one transaction at a time; for instance, in the simulation, the Configuration Control Board (CCB) is considered a facility because only one engineering change proposal (ECP) is reviewed at a time. A storage can process multiple transactions. The capacity of a storage or the number of transactions can be specified or the GPSS compiler program will assign the capacity as $(2^{31} - 1)$. A keypunch operation is considered as a storage, since, for example, the Maintenance Directorate may have three keypunch machines and three operators available. A queue or waiting line accounts for the amount of time a transaction is delayed from entering a facility or storage. All facilities and storages had queues associated with them.

An iteration consists of tracing the flow of a provisioning effort from initiation to termination. When establishing times used in the model, it was agreed that a provisioning effort would consist of processing five hundred selection worksheets (SW) through the system. A selection worksheet is the basic building block for a provisioning effort. Each selection worksheet contains all the provisioning data for each component of the system that is identified by a manufacturer's part number or reference number (REFNO). Initially, these worksheets are prepared by hand and verified. They are then keypunched and processed through CCSS and are converted to automated SW overprints. This action creates the Provisioning Master Data Record (PMDR) and other provisioning related files. The need to create the selection worksheets by hand will be virtually eliminated once the use of Logistical Support Analysis (LSA) is fully implemented. A bridging program will convert the data generated by LSA directly into the CCSS files and all selection worksheets will be overprinted. This will eliminate the time needed to manually prepare the provisioning data for input to CCSS. LSA should also provide more accurate and complete initial input and redirect errors.

Table 1 compares the simulation results with the original March 1976 estimate.

TABLE 1. COMPARISON OF THE SIMULATION RESULTS WITH THE MARCH 76 MAINTENANCE AND MATERIEL MANAGEMENT DIRECTORATES ESTIMATE

Simulation	265 (Calendar Days)
Estimate (Mar 76)	239
Difference	26

The 26 day difference between the simulation results and the March 76 estimate was discussed with representatives of the Maintenance and Materiel Directorates. The consensus was that the number of days developed in the simulation was a truer representation of the length of time needed to complete a provisioning effort. The March '76 estimate did not fully account for the time needed to correct errors and the possible need for resubmission

of data for National Stock Numbers (NSN) to the Defense Logistics Service Center (DLSC) and Defense Supply Agency or General Services Administration (DSA/GSA).

V. SENSITIVITY ANALYSIS

The sensitivity of the following system factors was investigated:

a. There were six unfilled positions in the Provisioning Branch of the Maintenance Directorate. The opinion was that this shortage of personnel created a backlog situation. These additional slots were incorporated into the simulation.

b. DLSC and DSA/GSA are allowed 60 days to screen the NSN Master Data Record (NSNMDR) for stock numbers or assign stock numbers. If the submitted data contains errors, corrections must be made and the data resubmitted. DLSC and DSA/GSA are then allowed an additional 60 days to process the data. The number of days to process data was artibrarily reduced to 30 and incorporated into the simulation.

c. Logistical Support Analysis (LSA) is a required procedure to be followed. However, this procedure is not fully implemented as yet for various reasons. Complete use of LSA was incorporated and simulated.

VI. SENSITIVITY RESULTS

a. Increase the number of personnel in the Provisioning Branch. The capacity of the storage entity titled Provisioning Branch was increased by six and no other changes were made in the simulation model. The results are shown in Table 2.

TABLE 2. INCREASE THE NUMBER OF PROVISIONING PERSONNEL BY SIX

Time with Current Personnel	265 (Calendar Days)
Time with Six Additional Personnel	261
Difference	4

While the addition of six personnel to the Provisioning Branch did decrease the provisioning time frame by four days, it is doubtful that the cost of additional personnel would be warranted. To substantiate this, the increased number of personnel was varied from six down to two and the reduction in provisioning time only changed from four days to three days. The addition of only one person resulted in a reduction of one day.

b. Reduce the DLSC and DSA/GSA Process Time. The reduction of process time used in this simulation was from 60 to 30 days; all other portions of the simulation remained unchanged. While a reduction in this time frame is not within HQ, ARRCOM's control, the results shown in Table 3 indicate the effect of revising the 60-day process time.

TABLE 3. REDUCED PROCESS TIME - DLSC AND DSA/GSA

Current 60-day Process Time	265 (Calendar Days)
30-day Process Time	179
Difference	86

The reduced times for DLSC and DSA/GSA made a significant contribution in reducing the provisioning time. Since on occasion DLSC and DSA/GSA have responded in a rapid manner (1-15 days), it appears that a reduction in the 60 days may be reasonable. If the 60-day limit remains absolute, time still can be saved if error resubmission is placed in a category that waives the 60-day process time.

c. Implement Logistical Support Analysis (LSA). Logistical Support Analysis procedures are required to be performed on all newly developed weapon systems and for major modifications to an existing system. This requirement, however, is currently not fully implemented because of difficulties with the bridging program that converts the LSA data into CCSS format and because of the need to thoroughly familiarize personnel with LSA procedures. The complete use of LSA in the Provisioning Process was simulated and the results are shown in Table 4.

TABLE 4. EFFECT OF LSA PROCEDURES

Current Process (Limited Use of LSA)	265 (Calendar Days)
Complete Use of LSA	235
Difference	30

The use of LSA is an existing DARCOM requirement and training in the use of LSA is available. If cost savings can be identified, the rapid implementation of LSA may be warranted.

d. Complete use of LSA procedures and increase the number of personnel in the Provisioning Branch by Six. The complete use of LSA procedures and the effect on additional six provisioning personnel were simulated. This combination was chosen because HQ, ARRCOM can readily implement these changes. The results are shown in Table 5.

TABLE 5. EFFECT OF LSA PROCEDURES AND AN INCREASE IN PROVISIONING PERSONNEL

Current Process	265 (Calendar Days)
LSA and Increased Personnel	235
Difference	30

The results of this simulation run are identical with Table 4 (LSA). Further investigation revealed that the Provisioning Branch experienced

no queue time when LSA procedures were used. Since provisioning procedures would require the same time to perform, excluding queue time, increasing the available number of personnel when no backlog exists would not create a reduction in time.

VII. SUMMARY

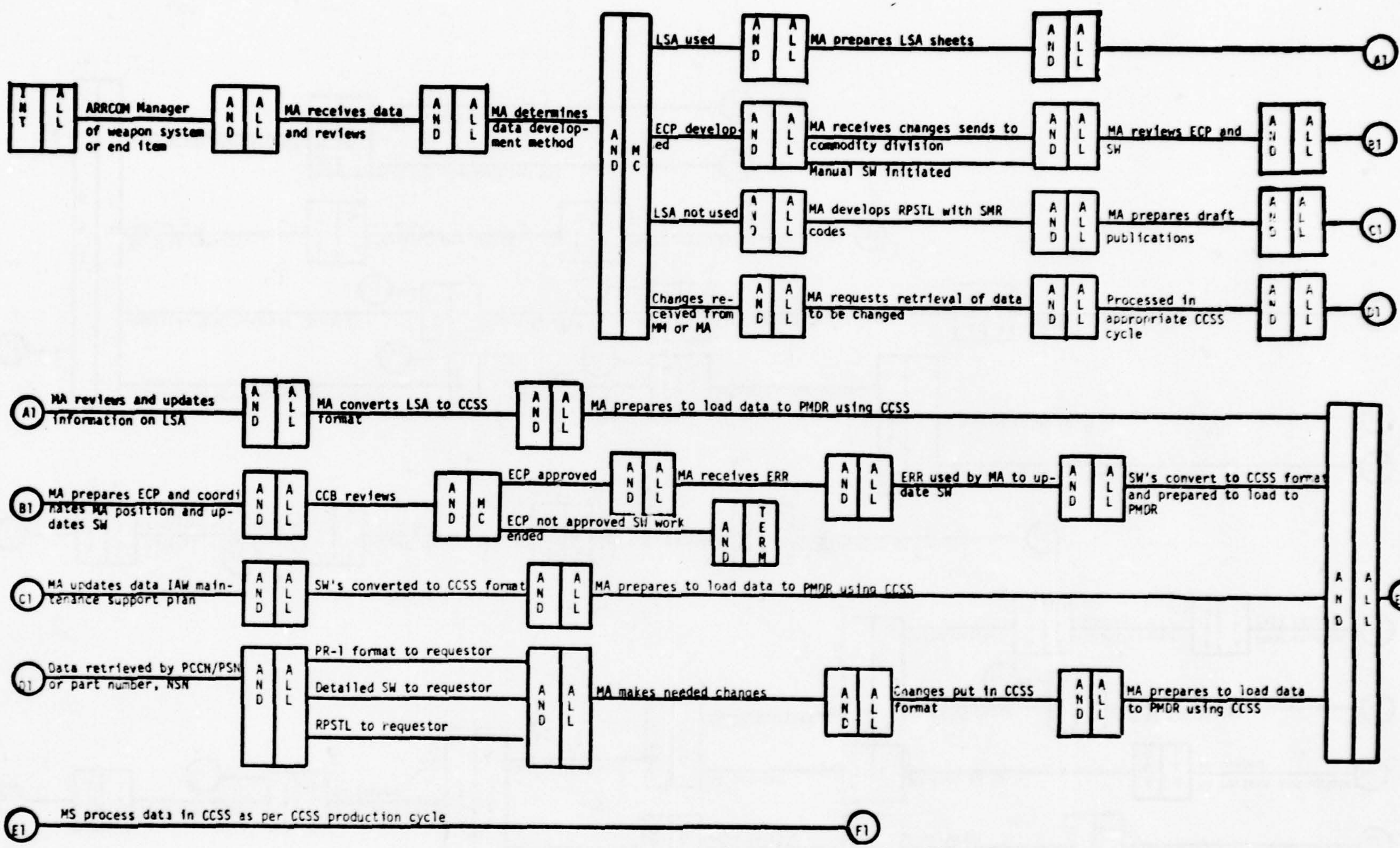
The results of implementing changes in the current provisioning process indicate the following:

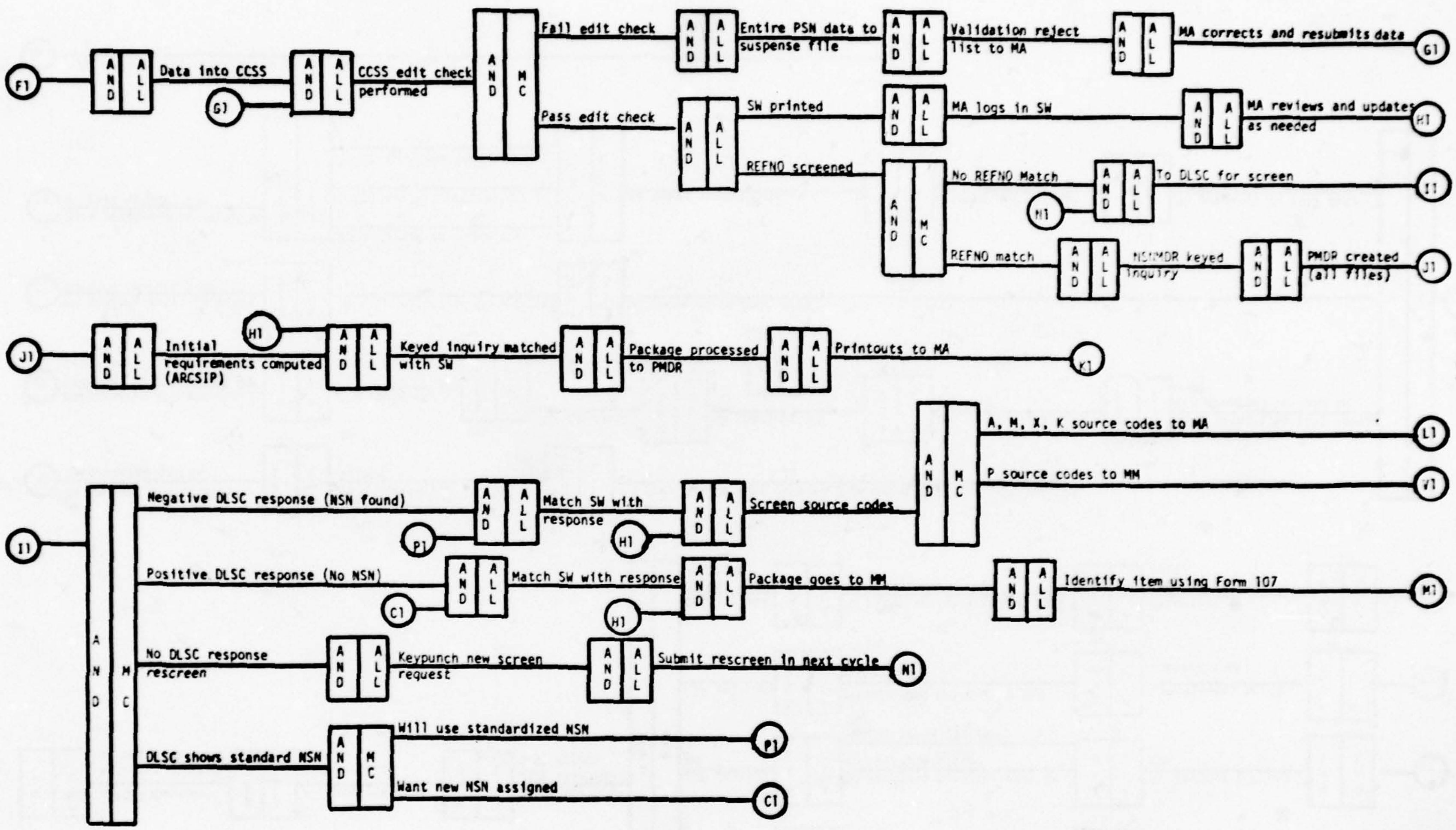
a. Reducing DLSC and DSA/GSA 60-day allowance for response can result in the greatest reduction in time. However, this solution is not immediately feasible because it requires DoD level action.

b. Increasing the provisioning personnel results in the least time reduction. Before this solution is implemented, the cost of additional personnel vs a one to four day time savings should be investigated.

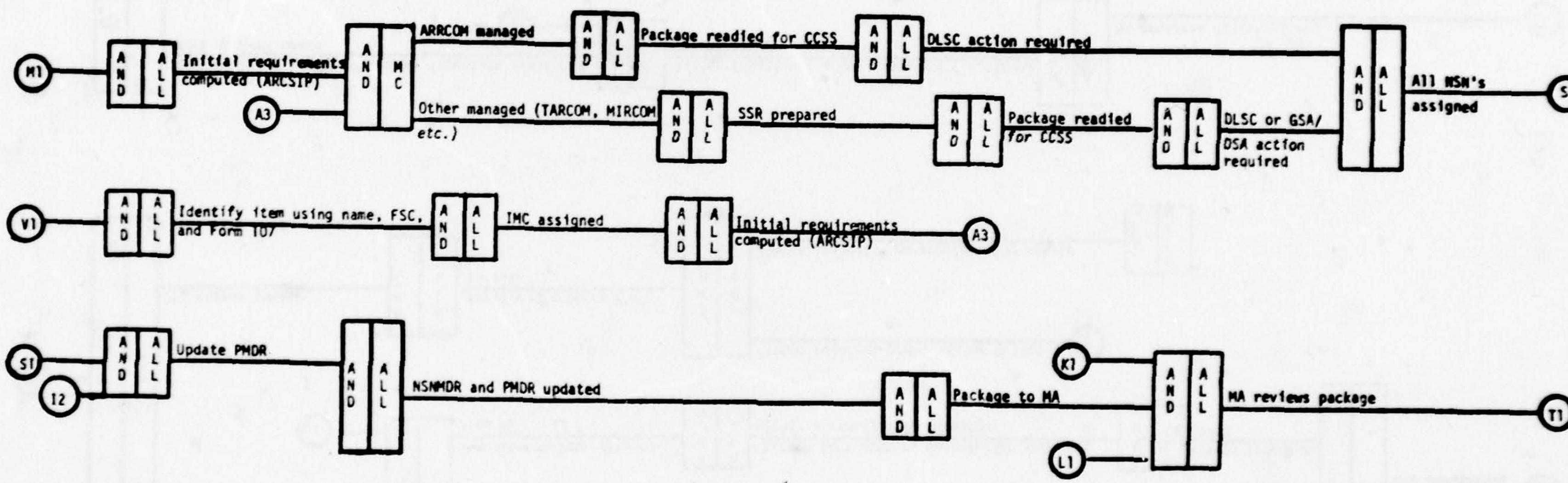
c. Implementing the LSA and increased personnel alternative is not viable because increasing the number provisioning personnel had no effect on time when combined with the use of LSA.

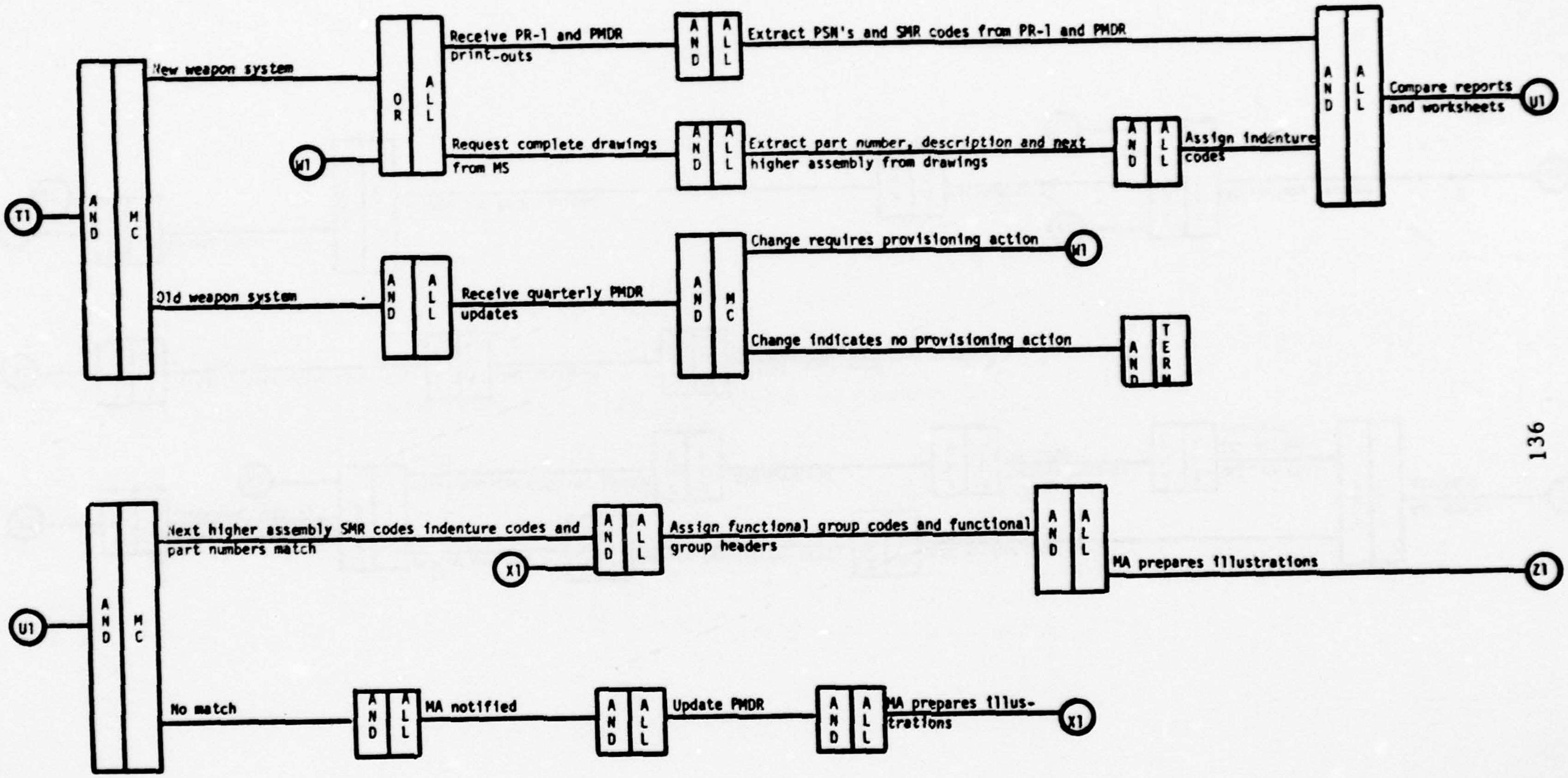
d. Using LSA extensively is the most feasible solution. However, this action requires special effort to solve any exisitng bridging problems and requires that proper LSA training be made available on a large scale.

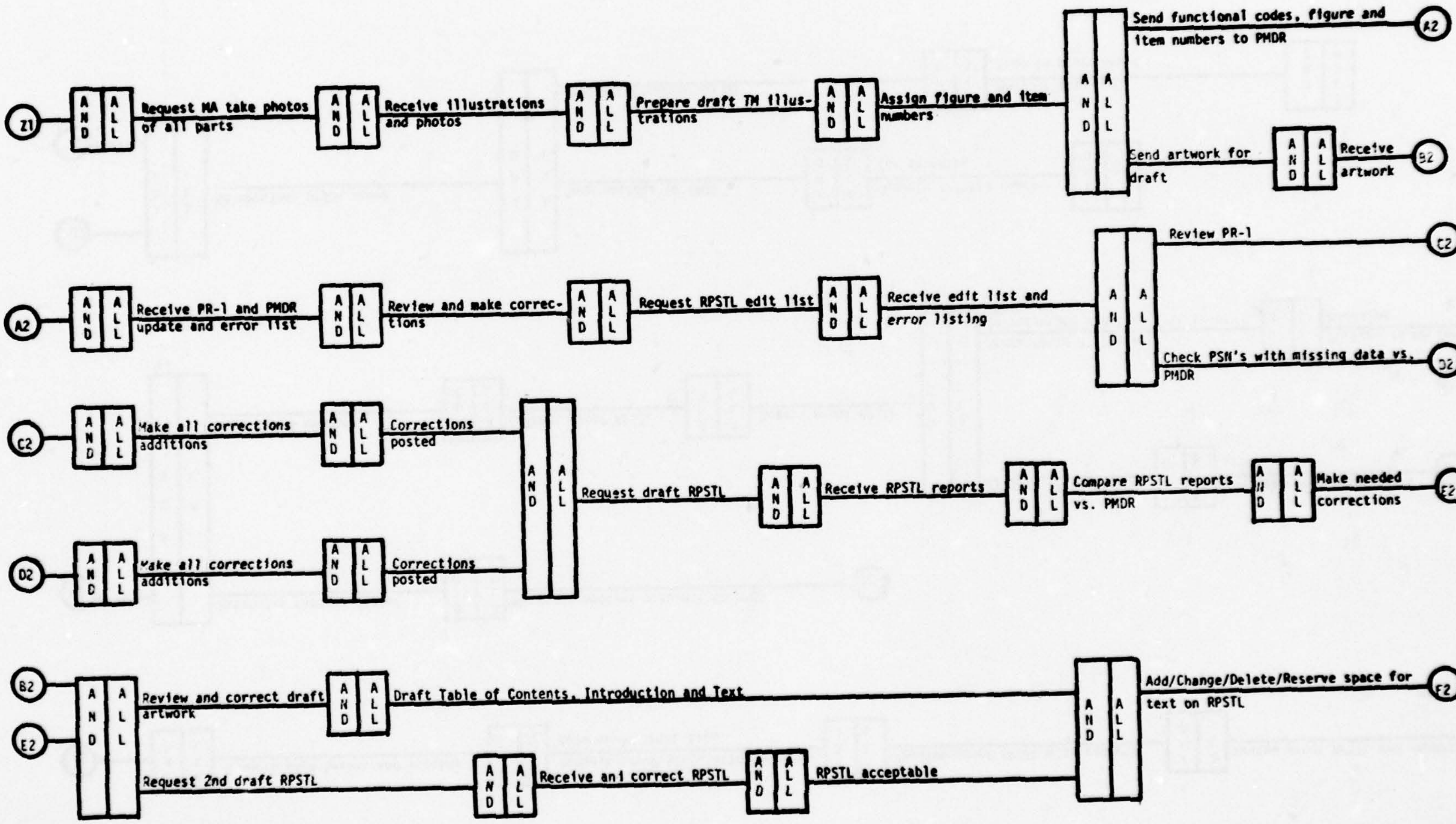

ARRCOM Manager of weapon system or end item
MA receives data and reviews
MA determines data development method
LSA used
MA prepares LSA sheets
ECP developed
MA receives changes sends to commodity division
Manual SW initiated
MA reviews ECP and SW
LSA not used
MA develops RPSTL with SMR codes
MA prepares draft publications
Changes received from MM or MA
MA requests retrieval of data to be changed
Processed in appropriate CCSS cycle
MA reviews and updates information on LSA
MA converts LSA to CCSS format
MA prepares to load data to PMDR using CCSS
MA prepares ECP and coordinates MA position and updates SW
CCB reviews
ECP approved
ECP not approved SW work ended
MA receives ERR
ERR used by MA to update SW
SW's convert to CCSS format and prepared to load to PMDR
MA updates data IAW maintenance support plan
SW's converted to CCSS format
MA prepares to load data to PMDR using CCSS
Data retrieved by PCCN/PSN or part number, NSN
PR-1 format to requestor
Detailed SW to requestor
RPSTL to requestor
MA makes needed changes
Changes put in CCSS format
MA prepares to load data to PMDR using CCSS
MS process data in CCSS as per CCSS production cycle

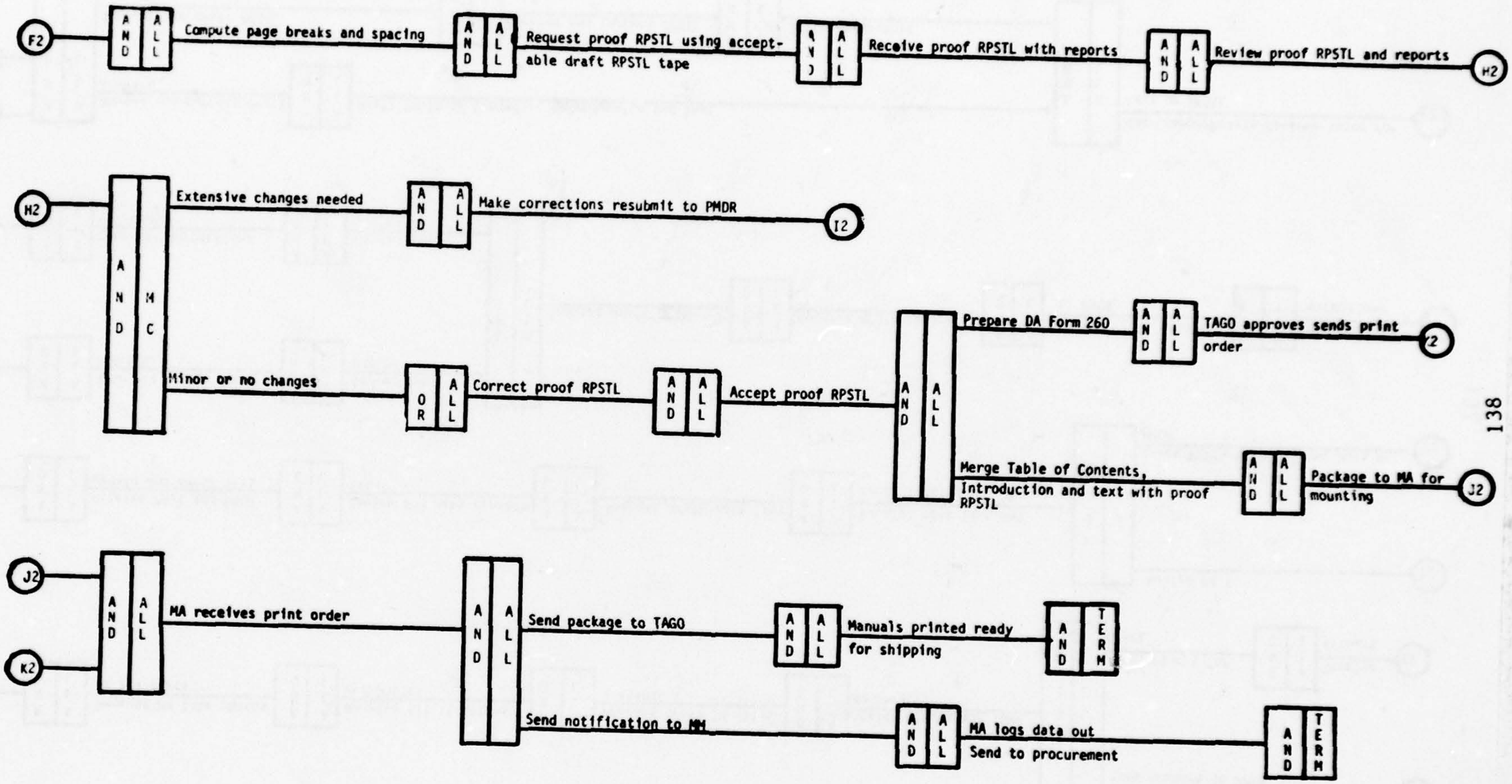


F1
AND ALL
Data into CCSS
G1
AND ALL
CCSS edit check performed
AND MC
Fail edit check
AND ALL
Entire PSN data to suspense file
AND ALL
Validation reject list to MA
AND ALL
MA corrects and resubmits data
G1
Pass edit check
AND ALL
SW printed
AND ALL
MA logs in SW
AND ALL
MA reviews and updates as needed
H1
REFNO screened
AND MC
No REFNO Match
N1
AND ALL
To DLSC for screen
I1
REFNO match
AND ALL
inquiry
AND ALL
PMDR created (all files)
J1
J1
AND ALL
Initial requirements computed (ARCSIP)
H1
AND ALL
Keyed inquiry matched with SW
AND ALL
Package processed to PMDR
AND ALL
Printouts to MA
K1
I1
AND MC
Negative DLSC response (NSN found)
P1
AND ALL
Match SW with response
H1
AND ALL
Screen source codes
AND MC
A, M, X, K source codes to MA
L1
P source codes to MM
V1
Positive DLSC response (No NSN)
C1
AND ALL
Match SW with response
H1
AND ALL
Package goes to MM
AND ALL
Identify item using Form 107
M1
No DLSC response rescreen
AND ALL
Keypunch new screen request
AND ALL
Submit rescreen in next cycle
N1
DLSC shows standard NSN
AND MC
Will use standardized NSN
P1
Want new NSN assigned
C1


M1
AND ALL
Initial requirements computed (ARCSIP)
A3
AND MC
ARRCOM managed
Other managed (TARCOM, MIRCOM etc.)
Package readied for CCSS
DLSC action required
SSR prepared
Package readied for CCSS
DLSC or GSA/DSA action required
All NSN's assigned
S1
V1
Identify item using name, FSC, and Form 107
IMC assigned
Initial requirements computed (ARCSIP)
A3
S1
I2
Update PMDR
NSNMDR and PMDR updated
Package to MA
K1
L1
MA reviews package
T1


T1
AND MC
New weapon system
Old weapon system
OR ALL
W1
Receive PR-1 and PMDR print-outs
Request complete drawings from MS
AND ALL
Extract PSN's and SMR codes from PR-1 and PMDR
AND ALL
Extract part number, description and next higher assembly from drawings
AND ALL
Assign indenture codes
AND ALL
Compare reports and worksheets
U1
AND ALL
Receive quarterly PMDR updates
AND MC
Change requires provisioning action
W1
Change indicates no provisioning action
AND TERM
U1
AND MC
Next higher assembly SMR codes indenture codes and part numbers match
X1
AND ALL
Assign functional group codes and functional group headers
AND ALL
MA prepares illustrations
Z1
No match
AND ALL
MA notified
AND ALL
Update PMDR
AND ALL
MA prepares illus-trations
X1


Z1
AND ALL
Request NA take photos of all parts
AND ALL
Receive illustrations and photos
AND ALL
Prepare draft TM illustrations
AND ALL
Assign figure and item numbers
AND ALL
Send functional codes, figure and item numbers to PMDR
A2
Send artwork for draft
AND ALL
Receive artwork
B2
A2
AND ALL
Receive PR-1 and PMDR update and error list
AND ALL
Review and make corrections
AND ALL
Request RPSTL edit list
AND ALL
Receive edit list and error listing
AND ALL
Review PR-1
C2
Check PSN's with missing data vs. PMDR
D2
C2
AND ALL
Make all corrections additions
AND ALL
Corrections posted
D2
AND ALL
Make all corrections additions
AND ALL
Corrections posted
AND ALL
Request draft RPSTL
AND ALL
Receive RPSTL reports
AND ALL
Compare RPSTL reports vs. PMDR
AND ALL
Make needed corrections
E2
B2
E2
AND ALL
Review and correct draft artwork
AND ALL
Draft Table of Contents, Introduction and Text
Request 2nd draft RPSTL
AND ALL
Receive ani correct RPSTL
AND ALL
RPSTL acceptable
AND ALL
Add/Change/Delete/Reserve space for text on RPSTL
F2


F2
AND ALL
Compute page breaks and spacing
AND ALL
Request proof RPSTL using acceptable draft RPSTL tape
AND ALL
Receive proof RPSTL with reports
AND ALL
Review proof RPSTL and reports
H2
H2
AND MC
Extensive changes needed
AND ALL
Make corrections resubmit to PMDR
I2
Minor or no changes
OR ALL
Correct proof RPSTL
AND ALL
Accept proof RPSTL
AND ALL
Prepare DA Form 260
AND ALL
TAGO approves sends print order
Merge Table of Contents, Introduction and text with proof RPSTL
AND ALL
Package to MA for mounting
J2
J2
K2
AND ALL
MA receives print order
AND ALL
Send package to TAGO
AND ALL
Manuals printed ready for shipping
AND TERM
Send notification to MM
AND ALL
MA logs data out
Send to procurement
AND TERM

ARCSIP - Automated Requirements Computation System Initial Provisioning
ARRCOM - US Army Armament Materiel Readiness Command
CCB - Configuration Control Board
CCSS - Commodity Command Standard System
DLSC - Defense Logistics Service Center
ECP - Engineering Change Proposal
ERR - Engineering Release Record
FSC - Federal Supply Category
GSA/DSA - General Services Administration/Defense Supply Agency
IMC - Item Management Code
LSA - Logistical Support Analysis
MA - Maintenance Directorate
MM - Materiel Management Directorate
MS - Management Information Systems Directorate
NSN - National Stock Number
NSNMDR - National Stock Number Master Data Record
PCCN - Provisioning Contract Control Number
PMDR - Provisioning Master Data Record
PR-1 - Provisioning Requirement - Initial
RPSTL - Repair Parts Special Tools List
SMR - Source Maintenance Recoverability
SSR - Supply Support Request
SW - Selection Worksheet
TAGO - The Adjutant General's Office
TM - Technical Manual

TITLE: US Strategic Base Requirements

AUTHOR: Mr. Dean E. Considine

AGENCY: US Army Engineer Studies Group (ESG)

--INTRODUCTION--

BACKGROUND

During 1976, the Engineer Studies Group (ESG) completed a study of US strategic mobility base requirements for the Department of the Army, Deputy Chief of Staff for Operations and Plans (DCSOPS). The study was prompted by difficulties encountered when the US airlifted supplies to the Middle East during the 1973 Arab-Israeli war. Of particular concern was the apparent ease with which either base operating rights or over-flight rights can be lost in time of crisis. The Army Staff, therefore, decided that the US overseas basing posture needed to be examined and that the examination should compare projected base assets with anticipated future requirements to find any deficiencies (or excesses). The ESG study provided such an examination.

The study identified the type, location, and physical characteristics of strategic mobility bases required to support a wide range of contingencies during the 1980 to 1990 period. It also identified those bases required to maximize strategic deployment capabilities against all possible contingencies throughout the world. Using these basing needs as an envelope of requirements, the study provided an Army position concerning the need for US strategic mobility bases worldwide.

BASE SELECTION CRITERIA

The study examined a multitude of candidate base locations. Some bases were located on US territory, others were existing US bases on foreign territory, and still others were at foreign locations where the US presently has no base rights. Each base location was examined relative to three criteria--the bases' ability to support strategic deployments (the most important criteria), the political constraint (foreign) associated with the retaining/acquiring base rights, and the development potential (including construction costs) of each base candidate.

TOPIC OF THIS PAPER

The first criteria (support of strategic deployments) is the topic of this paper. More specifically, this paper describes the methods used to measure the strategic value of alternative base locations. Strategic value was measured in terms of the deployment tonnages each base location could support relative to a specific set of contingencies. The strategic value of specific base locations varied depending on the mobility fleet's characteristics and the number and location of the contingencies the base may be required to support. To avoid security classification, this paper does not discuss the strategic value of alternative base locations

in terms of supporting specific contingencies. Instead, it discusses strategic value in terms of the bases' abilities to support more general contingencies on a regional, multiregional, and worldwide basis. Also to avoid security classification, the paper considers a general, rather than a specific, mobility fleet.

TYPES OF BASES

Before proceeding to the study method, strategic deployment bases need to be defined. Strategic deployment bases are those required outside CONUS to project US combat power into an objective area during the initial stages of a contingency operation. The study considered two types of bases (doing the functions listed) in the following priority:

. Strategic mobility air base

  . Staging area for deploying forces

  . Refueling base for strategic deployment aircraft

  . Support base for tanker aircraft (when required)

  . Logistic support base (initial resupply only) for deployed forces (when required)

Strategic mobility sea bases

  . Initial resupply of deployed forces (when required)

CONTINGENCY AREAS

As noted above, the ESG study determined strategic deployment base requirements to support specific contingencies throughout the world. However, it also determined the value of (and need for) similar bases to support contingencies that might occur anywhere within more general regions of the world. To accomplish the latter objectives, the world was viewed three ways. The first was ten regions covering the entire world, less the communist block countries, Central Europe, and North America (see Figure 1). (The Communist bloc countries and North America were fenced out for obvious reasons. Central Europe was fenced out since strategic deployment to that area had been examined repeatedly in many recent studies.) The second way was the same "world" but divided into onl four multiregions (see Figure 2). The third way was the same world, but viewed as a single world region. Dividing the world this way allows the decisionmaker to select the most effective base locations for support contingencies in areas he choses. For example, if the US planned or expected to assist an ally militarily in only certain areas of the world, (i.e., Region 5 of Figure 1 or multiregion B of Figure 2), the most effective base location to support a military contingency in only those regions would be known.

REGIONAL BOUNDARIES

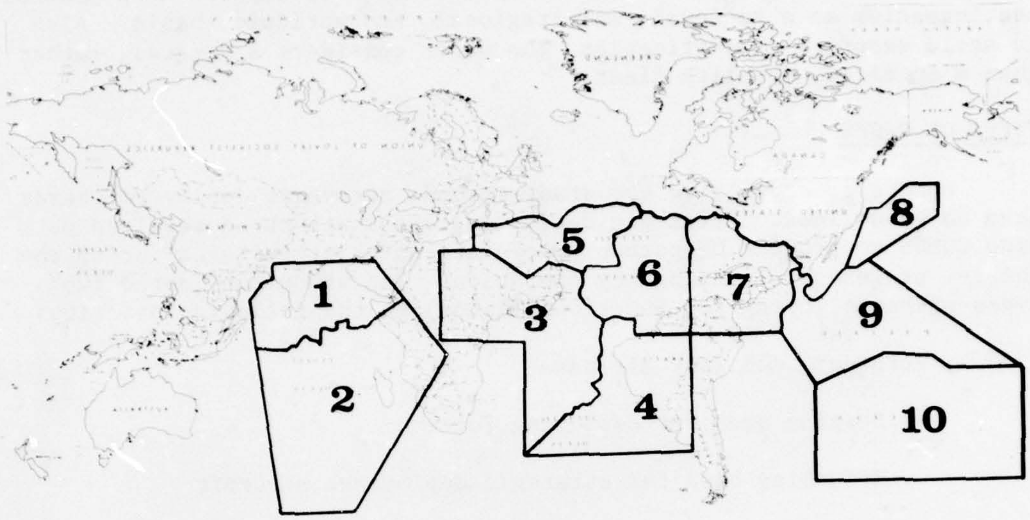


Figure 1

MULTIREGIONAL BOUNDARIES

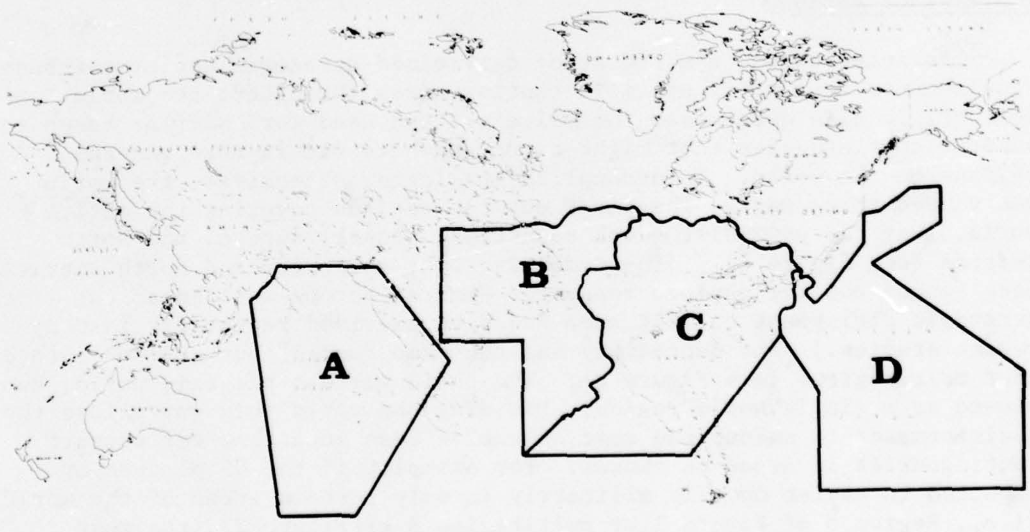
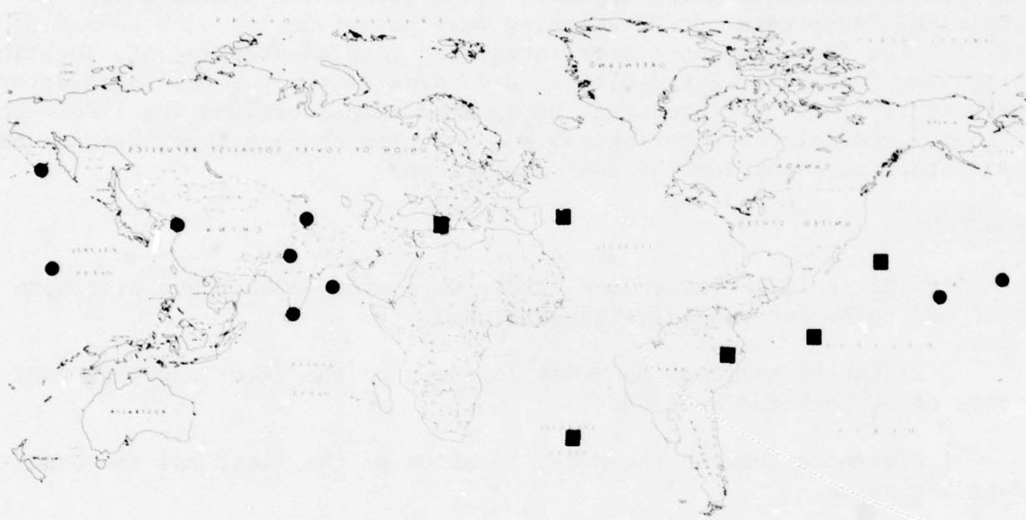


Figure 2

CANDIDATE BASE LOCATIONS

The ESG study examined more than 60 foreign locations as candidates for a future site of a US air or sea base. The candidate locations were arbitrarily selected to provide worldwide coverage. Although additional candidate locations could have been examined, it was found that their support capabilities could be closely approximated by interpolating between the results of the examined candidate locations. Figure 3 shows an example of a few possible candidates. These foreign base candidates (not necessarily addressed in study) are used throughout this paper to demonstrate the study method. Throughout the study, maximum advantage was taken of existing US bases on US territory (or trust territories).

CANDIDATE AIR & SEA BASE LOCATIONS



● US BASES (Complete list)

■ FOREIGN BASES (Example)

Figure 3
--SEA BASE ANALYSIS--

GENERAL METHOD

The relative capability of alternative sea base locations was determined by conducting sea deployment simulations under various operating assumptions. The simulations were conducted using a sea deployment model developed by ESG. Model inputs consist of route distances and the number, physical characteristics, and starting locations of each ship in the sealift fleet. The model simulates sea deployments and resupply over alternate routes with the sealift fleet moving supplies from CONUS and assumed prepositioned stocks from the forward logistic sea bases to the

various contingency areas. Outputs are the time-phased (daily) tonnage of material delivered to each contingency area. Differences in time-phased tonnage delivered to the contingency areas are used as the general measure of relative capability of alternative sea base candidates.

SEALIFT FLEET

The value of a forward logistic sea base depends on both its proximity to the contingency area and the M-day location of the sealift fleet. A base located near a contingency area requires few days per round trip to shuttle supplies, but bases located on or near principal world navigation routes are most likely to have US flagships nearby when the emergency occurs. The Military Sealift Command (MSC) Integrated Sealift System (ISS) group maintains files on all US and foreign flagships. ISS can locate these ships anytime. On request, ISS provided ESG the empirical "snapshots" of US shipping on 4 days (one for each season of 1975). The four snapshots were integrated into an average ship location situation for 1975. Extrapolation according to the changes in inventory between 1975 and 1980 produced the assumed ship locations for 1980. The number, physical characteristics, and location of each type ship served as a starting point for the ESG simulations.

ROUTE DATA

In the sealift simulations, there were over 4,000 route distances that had to be determined. They included:

. Distances between the M-day location of the fleet and the CONUS ports of Norfolk and Oakland.

. Distances between the M-day location of the fleet and the candidate sea bases.

. Distances between the candidate sea base locations and the contingency areas.

. Distances between the three contingency areas and the CONUS ports of Norfolk and Oakland.

SEALIFT MODEL

Three basic assumption variables were fixed for each specific simulation run:

. Whether the no mobilization, partial mobilization, or full mobilization sealift fleet can be used.

. Whether there are any sealift constraints (i.e., Suez Canal closed for transit).

. Which candidate sea base location would be used for a forward logistic sea base.

For each simulation, a fixed number of ships closest to the forward sea base were manually identified. The days sailing time from their snapshot locations to the intermediate base was computed and fed to the model. On a hypothetical alert day (M-day), the model routed each of these ships to the intermediate base to pick up military cargo for delivery to the contingency area. After the first delivery to the contingency area, the model shuttled the ship between the contingency area and the nearest CONUS port (Norfolk or Oakland) for the rest of the simulation.

In each simulation, the sealift model examined the first ship in the fleet arriving at a CONUS port and computed its 60-day delivery capability to each of the independent contingency areas. It then processed succeeding ships in the fleet until it considered all of them. Ships were routed by the model to the most productive CONUS port (Norfolk or Oakland). That routing was based on a "look ahead" routine which computed the shortest route from the ships' M-day location to the contingency area via either of the two CONUS ports. Once the ships arrived at the contingency area, they were shuttled to the nearest CONUS port. The model accumulated and printed out a day-by-day record of the cargo delivered to each contingency area.

MEASURE OF EFFECTIVENESS

The logistic sea base analysis was designed to determine relative capabilities of the sealift fleet when used both with and without a forward logistic sea base. This increase in capability can be measured in two ways: relative to the deployment requirements and relative to the timeliness of the increased deployment capability. The measure of effectiveness used in the ESG study considered both.

. Deployment Requirements

ESG considered three sets of deployment requirements. Two were based on the deployment requirements within a specific contingency area. The third was a more general regional, multiregional, and worldwide requirement.

. Contingency Area Requirement.

ESG developed the deployment requirements for each specific contingency examined in the study. A forward logistic sea base was considered effective only if it helped support those requirements. Figures 4 and 5 show how this contribution was measured.

. Net Requirement.

Figure 4 shows the sealift deployment capabilities, with and without a forward logistic sea base. It also shows the contingency area deployment requirement and that portion of the total requirement that can be supported by air deployments. The shaded area in Figure 4

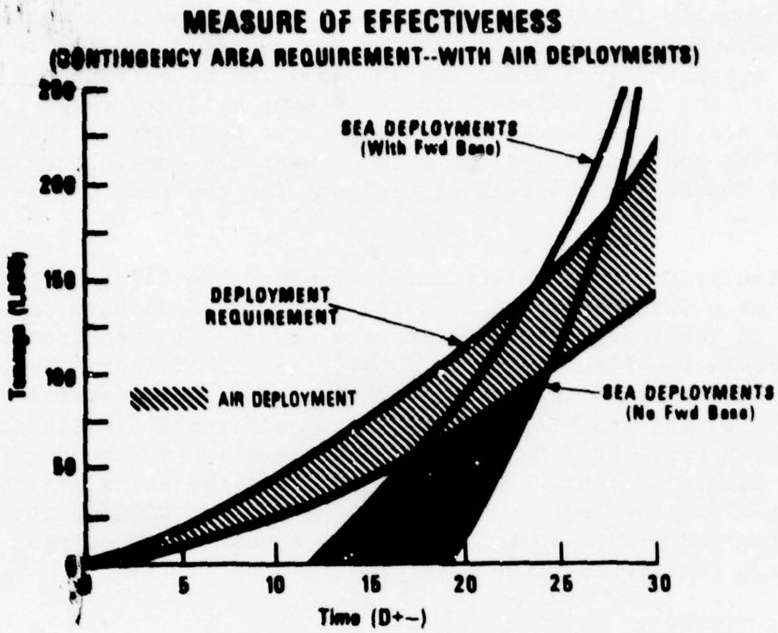


Figure 4

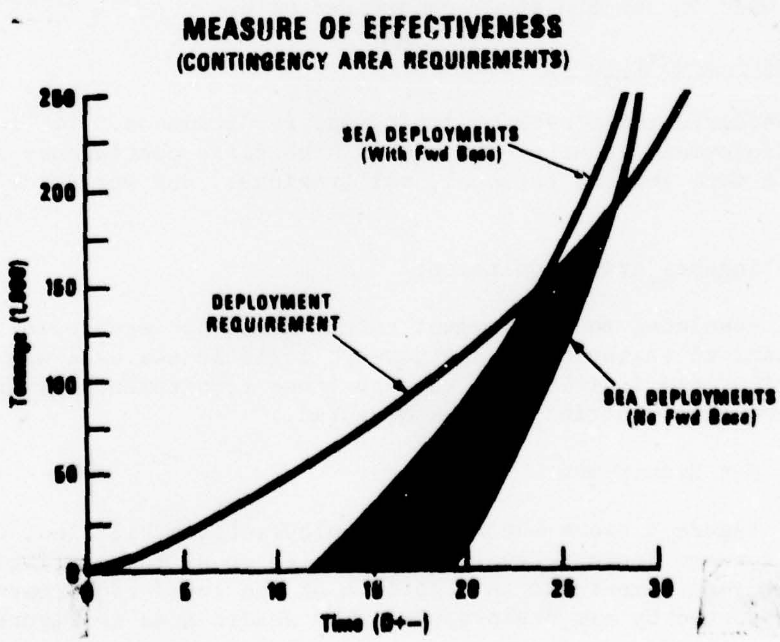


Figure 5

is considered the forward logistic sea base's measure of effectiveness. The shaded area represents the increase in the deployment tonnage generated through using the forward logistic base. That increase, however, is limited by the net requirement (i.e., gross requirement less those requirements that can be satisfied by air deployment).

. Gross Requirements.

Figure 5 shows the same sealift deployment capabilities, with and without a forward logistic sea base. It also shows the same contingency area deployment requirement, but without air deployments. The shaded area in Figure 5 is the forward logistic sea base's measure of effectiveness without reliance on air deployments. This measure of effectiveness was considered useful when overflight rights are not assured and air deployments cannot be made.

. Regional, multiregional, and worldwide requirements.

Although the specific contingencies examined in the ESG study were a best estimate of mid-range requirements, they still could change, both in size and location. As a hedge against that possibility, a logistic sea base's value was also measured in terms of its ability to support more general contingencies. It was assumed that the contingencies could occur anywhere within the 10 regions shown in Figure 1 and could be larger in magnitude. Also, unexpected loss of base facilities and operating rights may prevent air deployments. Under these extreme conditions, the value of a forward logistic sea base would be increased substantially. Figure 6 shows how the ESG study measured the effectiveness of a forward logistic base under those extreme conditions. Similar to Figure 5, this figure shows sea deployment capabilities with and without a forward logistic sea base. These sea deployment capabilities, however, are an average of the sea deployment capabilities into all contingency areas within a region. Similarly, to measure capabilities on a regional, multiregional, and worldwide basis, the study used the average of the sea deployment capabilities across all contingency areas throughout a region, multiregional area, or the world. Thus, the difference in average sea deployment capabilities (with and without a forward base) was used as the measure of effectiveness of alternative logistic sea bases to support contingency operations on a regional, multiregional, and worldwide basis. The deployment requirements shown in Figure 6 are arbitrarily high (assumes that contingency requirements may increase) and include no air deployments (assumes overflight rights are not granted). This measure of effectiveness can be viewed as a more general assessment of mid-range capabilities. Since the sealift fleet is not expected to change dramatically, it can also be viewed as an assessment of long-range capabilities generated by the use of the forward logistic sea base.

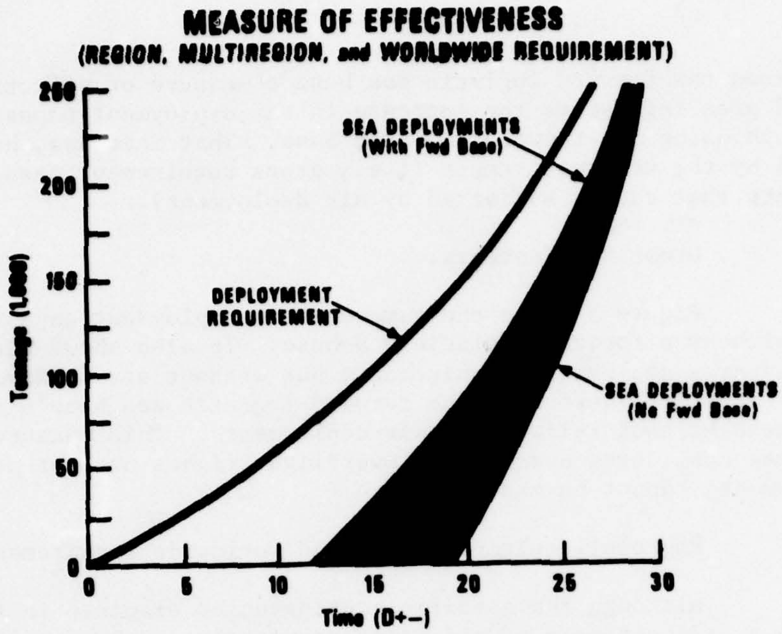


Figure 6

. Timeliness of deployments.

The deployment tonnage increases gained through using a forward logistic sea base only partially measure the effectiveness of alternative base candidates. The timeliness of the increased deployment capability is a second measure of effectiveness. For example, two forward logistic sea bases might produce similar increases in deployment tonnages; but one base's increase might occur 1, 2, or 3 days earlier than the other. Each base would have a different value since the purpose of forward logistic sea bases is to improve the US rapid deployment capability (i.e., deploy not only as much as necessary but as soon as possible). Thus, the measure of effectiveness used to evaluate alternative sea bases should reflect that difference in value.

. Moment.

In order to measure both the deployment tonnage and when it was delivered, the ESG study used a first moment about a reference axis at D+60. The first moment calculated in this manner gave credit for a larger tonnage and/or earlier deployment closure--a desired result. For example, the tonnage deployed at D+13 is multiplied by 47 days (D+60 less D+13), and the tonnage arriving at D+14 is multiplied by 46 days. Thus, a ton deployed at D+13 is weighted 1 day heavier than a ton deployed at D+14. The first moment is the sum of the products (moment arm times tonnage delivered) for all 60 days.

. Illustration of first moment.

In Figure 7, the two shaded areas are similar to the shaded area in Figure 6. The left, right, and upper boundaries of the shaded area are, respectively, the cumulative tonnage delivered curve for the candidate base, the same curve for no base, and the net requirements curve. Because we are looking at three cumulative curves instead of the daily distribution curves, it turns out mathematically that the area of the shaded region is equal to the first moment. In other words, if the first moments for the candidate base and the no base case curves are calculated, their difference is exactly equal to the area of the shaded region. The dimension of the first moment or the area of the shaded region is STON-days and sea base "A" is 50 percent more effective than sea base "B" (i.e., 1,500,000 STON-days vs 1,000,000 STON-days). Thus, a first moment (STON-days) rather than simply increased deployments (STON) was used to measure the relative value of forward logistic sea bases. If these values are extended (averaged) to include all contingencies, they can be used to assess the value of alternative sea bases to support individual contingencies as well as all regional, multi-regional, and worldwide contingencies.

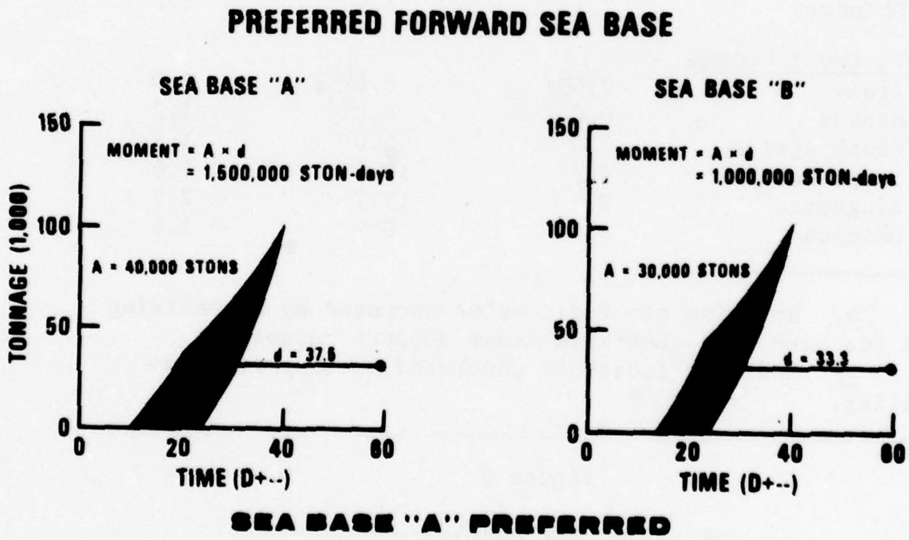


Figure 7

STRATEGIC VALUE OF SEA BASES

When all simulations were completed, the requirements for and the preferred location of strategic deployment sea bases to support specific contingencies were identified. Also identified were the preferred locations for sea bases to support regional, multiregional, and worldwide contingencies. The preferred locations actually varied depending on the level to which the US mobilized and the assumptions made regarding sealift constraints (i.e., Panama Canal open or closed). Figure 8 shows the type of data generated by the study. To avoid security classification, the data has been "dummied" and is keyed to no specific level of mobilization.

STRATEGIC VALUE OF SEA BASES

Sea Base Location and Constraint	Relative Support Capability[a] Region 1	Multiregion B	Worldwide
Suez Canal Open			
Italy	2.8	3.1	1.7
Azores	1.0	1.2	1.4
South Africa	1.0	1.0	1.0
Diego Garcia	2.8	3.7	1.8
Singapore	2.4	4.1	2.6
Okinawa	2.1	3.4	2.2
Suez Canal Closed			
Italy	0.0[b]	0.0[b]	1.0
Azores	0.0[b]	0.0[b]	1.2
South Africa	1.0	1.0	1.5
Diego Garcia	7.2	10.4	1.8
Singapore	7.8	13.7	2.2
Okinawa	6.7	8.9	1.6

a/ Relative strategic value computed by normalizing on sea base that generated least support capability.

b/ Sea base locations generated no support capability.

Figure 8

--AIR BASE ANALYSIS--

GENERAL METHOD

The relative capabilities of the candidate air bases to support strategic mobility aircraft were determined by conducting air deployment simulations under various operating assumptions. Simulations were conducted using an air deployment model also developed by ESG. Input to the model consisted of the air route data (length of each leg along all routes) and the number and operating characteristics of each aircraft type. The model simulated air deployment along each route to and through each candidate air base and on to each contingency area. Model output

was the average daily tonnage of materiel that can be delivered to each contingency area through each candidate air base. The following paragraphs discuss the inputs to the model, the model characteristics, and the use of model output to rank order the candidate air bases.

AIRLIFT FLEET

The aircraft inventory used in the simulations included the C-5 and C-141 for the Military Airlift Command (MAC) fleet and the 707 and 747 equivalent from the Commercial Reserve Air Fleet (CRAF). Availability of the aircraft varied with the level of mobilization and the time period considered. In the latter case, improvements in the airfleet are expected over both the mid- and long-term time period when the USAF's enhancement program is carried out. In the ESG study, three aircraft fleets (pessimistic, expected, and optimistic) were considered. The pessimistic fleet was considered to be the current fleet with no improvements. The expected fleet was considered to be the current fleet, but with the stretched version of the C-141 with aerial refueling capability. The optimistic fleet was considered to be the expected fleet with the Advanced Tanker Cargo Aircraft (ATCA) added.

ROUTE DATA

Basic to the data input were the distances from CONUS to each candidate base over each route and from each candidate base to each contingency area. The route data were composed of two elements: the path length from the aerial port of embarkation (APOE) in CONUS to the contingency areas and the lengths of legs along each path. The paths examined represented routes from the APOE to each intermediate base, paths between intermediate bases, and thence to all contingency areas. Paths to final bases may be either direct from the APOE or via other intermediate bases. Bases under US control were considered available in all contingencies. Political constraints sometimes made the availability of foreign bases contingency dependent. Because of overflight restrictions (some universally applied and some based on contingencies), paths between bases and from bases to contingency areas frequently detoured from the most direct routes. For example, moving from CONUS-west into the Indian Ocean, routes always bypassed Indochina. On the other hand, in some contingencies the Malay Peninsula could be crossed over southern Thailand; in others it was necessary to cross farther south over Malaysia; and in still others, no crossing of the peninsula at all was permissible, leaving only the Strait of Malacca for overflight. Thus, political as well as geographic considerations increased the number of routes examined. The study considered three different overflight assumptions: complete overflight, realistic (or contingency-dependent) overflight, and no overflight of non-US-controlled territory.

Under the realistic (contingency-dependent) overflight assumption, a total of 988 air routes was examined. All routes used McConnell Air Force Base (Wichita, Kansas) as the APOE. Of these 988 air routes, 835 went

west from CONUS; 153 went east from CONUS. The various contingency areas served as the aerial port of debarkation (APOD). Along each route, there were one to four intermediate air bases between the APOE and APOD. After the routes were selected, they were segregated into groups based on the number and ownership of candidate air bases that served each route. This segregation resulted in four sets of routes. One set consisted of routes served only by US-controlled bases. An example is a route originating at McConnell and passing through Elmendorf (Alaska) en route to the Republic of Korea. The other three route sets were those routes served by one, two, or three non-US-controlled bases. An example of the latter is a route originating at McConnell and passing through Alaska, Japan, Singapore, and Diego Garcia en route to a contingency in Region 6.

Under the complete overflight assumption, the air routes examined were the same as those used in the realistic assumption. The distinction was that under the realistic assumption, certain routes were not available in specific contingencies. Under the complete overflight assumption, the contingency-dependent route restrictions were removed. However, the complete overflight assumption retained some realism in that certain overflights are still precluded: overflights of Communist countries, of countries traditionally hostile to the US, and of US-aided countries' antagonists in a specific contingency.

Under the no overflight assumption, only the routes served by US-controlled bases were used. However, the length of the final leg into each contingency area was increased as required to reflect the no overflight assumption.

AIRCRAFT CHARACTERISTICS

The amount of cargo deliverable to a contingency area depends greatly on aircraft refueling operations. Refueling operations dictate aircraft payloads and ranges. Refueling in the contingency areas can greatly increase aircraft range or payload (usually referred to as allowable cabin load (ACL)). Likewise, aerial refueling on one or more legs of the route has the effect of enhancing aircraft distance and/or payload. In both cases, the amount of fuel the aircraft is required to carry directly affects payload. Therefore, a variety of operational modes were evaluated to cover fully the possible situations and possible fleets. Figure 9 illustrates 15 possible MAC aircraft operational modes involving refueling operations. These operational modes, when combined with the three potential fleets, (i.e., pessimistic, expected, optimistic) produce quite different air deployment capabilities. In each fleet, stress was placed on maximizing range in an attempt to minimize forward air base requirements.

MAC AIRCRAFT OPERATIONAL MODES[a/]

No aerial refueling (AR)
- No refueling in cntgcy area
- Selective refueling in cntgcy area[b/]
- Refueling in all cntgcy areas

No refueling in cntgcy area[b/]
- AR last leg only (depart)
- AR last leg only (depart & return)
- AR all legs (depart only)
- AR all legs (depart & return)

Selective refueling in cntgcy area[b/]
- AR last leg only (depart)
- AR last leg only (depart & return)
- AR all legs (depart only)
- AR all legs (depart & return)

Refueling in all cntgcy areas[b/]
- AR last leg only (depart)
- AR last leg only (depart & return)
- AR all legs (depart only)
- AR all legs (depart & return)

---

a/ CRAF aircraft have no aerial refueling capability.

b/ Contingency area dependent.

Figure 9

When aircraft can refuel in the contingency area, their radius mission range from CONUS is nearly doubled, or their payload on the outbound flight can be the maximum within the range limit. Aerial refueling on any leg of the mission also contributes to the range or payload. Because an aircraft uses considerable fuel on takeoff, aerial refueling shortly after takeoff can significantly increase the range with a fixed payload. Alternatively, aerial refueling shortly after takeoff can increase the payload over a fixed range if the cargo aircraft lifts off with an increased payload and reduced fuel load. Figure 10 graphically shows the range versus ACL tradeoff. This figure shows the variations possible in ACL and range for the C-5 and C-141 (stretch) through aerial refueling using the current KC-135 tanker and the proposed ATCA tanker. These and similar radius mission ACL-range curves for the CRAF aircraft were used in the air deployment simulations to evaluate the need for and the capabilities of alternative air base locations.

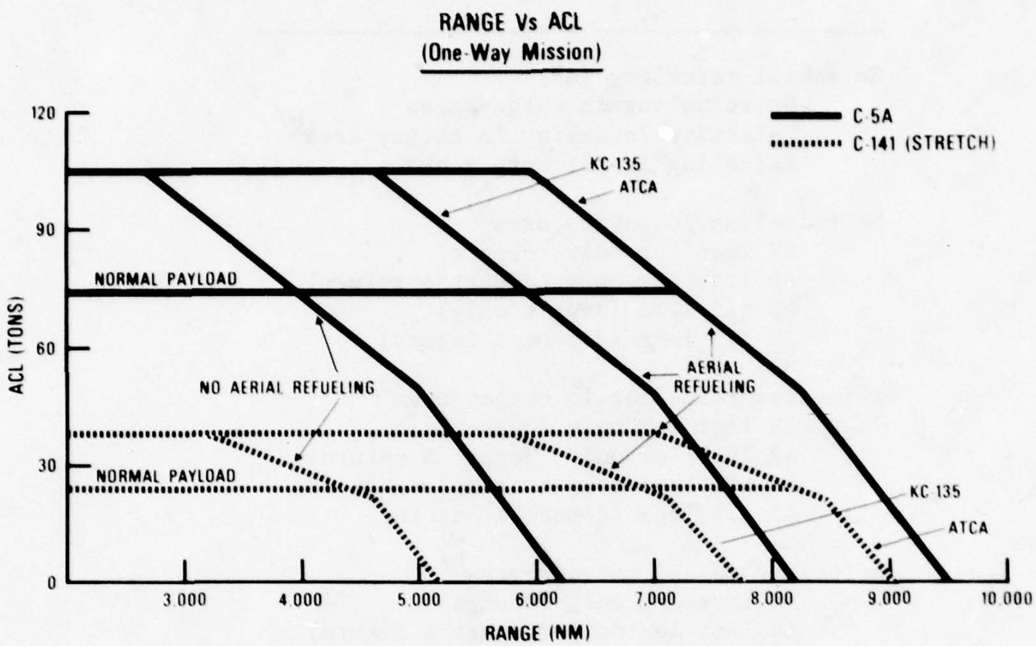


Figure 10

AIRLIFT MODEL

ESG developed an air deployment model to conduct all air deployment simulations with all the variables imposed by the number and type of aircraft, aircraft operational modes, and route distances. Originally developed to run on ESG's in-house WANG 2200 minicomputer, the model was subsequently converted to run on the Defense Mapping Agency Topographic Center's UNIVAC 1108 computer. The model is based on the formula shown below:

$$Ci = \frac{Vi \times Ni \times Ui \times Pi}{2 \times D}$$

Where Ci = daily deployment capability (STON) by aircraft type i
Vi = aircraft velocity in knots
Ni = aircraft number in fleet
Ui = utilization rate of aircraft type in fleet in hours per day (from Figure G-3-5)
Pi = payload of aircraft in STON
D = total length of route from APOE to APOD in nautical miles

The payload of aircraft type i (Pi) is calculated internally to the routine by evaluating maximum payload from two aircraft payload curves. One is for the longest leg prior to the last leg (a one-way mission curve), and one is for the last leg (from the last intermediate base to the contingency area) (a radius mission curve). The lesser of these two payloads is used to determine the overall payload of aircraft type i for a route. The total throughput capability along the route is the summation of capabilities for all fleet aircraft types.

The output of the model is the daily throughput to each contingency area along all routes leading to that area. Maximum throughputs for each final intermediate base into each contingency area are sorted by the base and contingency area. From this output, it is possible to select and rank order the best route, second best route, etc., into each contingency area. Since each route is dependent on one or more intermediate base(s), it is possible to select the best, second best, etc., intermediate base or combination of bases. Model output, as noted, is sensitive to operational mode and aircraft fleet, thus permitting a testing of each route (and intermediate base conbination) under all possible conditions.

STRATEGIC VALUE OF AIR BASES.

The ESG study identified the requirements for and the preferred location of strategic deployment air bases to support the specific contingencies addressed by the study. Also identified were the preferred location for air bases to support regional, multiregional, or worldwide contingencies. The preferred location actually varied depending on the airlift fleet (pessimistic, expected, optimistic) and overflight constraints (complete, realistic, or no overflights). Figure 11 is an example of the type of information generated by the study. As was done for the sea base results (Figure 8) and to avoid security classification, the information has been dummied and is keyed to no specific aircraft operational (refueling) mode or overflight constraint. The study determined the value of all candidate air bases for supporting strategic deployments on a regional, multiregional, and worldwide basis similar to the information on sea bases shown in Figure 8. However, Figure 11 shows the strategic value of alternative air base locations to support contingencies throughout the world and keyed to the airlift fleets.

STRATEGIC VALUE OF AIR BASES

Air Base Location	Relative Value by Aircraft Fleet[a/] Pessimistic (Current)	Expected (w/Improved 141)	Optimistic (w/ATCA)
CONUS-East Routes			
Italy	4.8	5.9	7.0
Azores	3.3	4.9	5.9
South Africa	1.1	1.9	4.3
McGuire	1.0	1.5	3.8
CONUS-West Routes			
Diego Garcia	2.7	2.9	4.0
Singapore	4.1	5.0	5.1
Okinawa	2.2	2.4	3.6
Wake	1.0	1.6	2.1

a/ Relative value was computed by normalizing on the air base that generated the least support capability for the pessimistic (current) aircraft fleet.

Figure 11

--SUMMARY--

The ESG study of US stratagic base requirements was not a traditional strategic deployment study. The study objective was not simply to determine strategic deployment capabilities. Rather, the objective was to determine the need for and preferred location of air and sea bases to maximize strategic deployment capabilities on an area, regional, multiregional, or worldwide basis. In accomplishing this objective, the study identified the number, location, type, and physical characteristics of the bases that the US must have to ensure a strategic deployment capability into various world areas. Stated another way, the study shows which foreign bases the US now has that should be retained and which foreign bases the US now has that could be given up without affecting our strategic deployment capabilities. Thus, the study provides a comprehensive base of information for DOD planning to use in making decisions on forward base alternatives. The study has been approved by both the DA and Joint Staff and is now being used for that purpose at both levels. This short paper provided only a brief description of the study method and very little on study results. For those readers interested in a more detailed description of study method, and especially the study results, it is suggested that they refer to the three-volume study report.

SUBJECT: Combat Damage - A Factor of Significance in Theater Army Force Structuring

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AGENCY: US Army Concepts Analysis Agency

This project, I like to imagine, required the amalgamation of several of the fundamental tools of systems analysis and the embodiment of those techniques that have become known as the scientific method called operations research. The more I think about it, however, the more I realize that no scientific barriers were besieged; that no new formulae were derived; that no new technical concepts were developed. The painfully honest conclusion I am forced to reach is that we were successful only in inspiring an informal group of concerned analysts to apply their considerable skills and the resources of their organizations toward resolution of an immediate, very real-world problem. This presentation is a report of that project and its results.

Slide 1

The problem was an Army force structuring problem. Specifically, it was a problem that dealt with the identification of field maintenance units in sufficient quantity and proper type to satisfy the maintenance requirements of a Theater Army engaged in a mid-intensity war in Europe.

Slide 2

The objective of the project, in even more specific terms, was to link a warfighting model to a support force roundout model so that the theater capability to repair combat vehicles could be used to describe the availability of repaired combat vehicles, the latter being a required input to the warfighting model.

Slide 3

The presentation will follow the outline shown here. The warfighting model involved was the Concepts Evaluation Model (CEM), a submodel that grew out of the FOREWON (Forces and Weapons) system of models. FASTALS is an acronym for Force Analysis Simulation of Theater Administrative and Logistic Support. In a moment we will briefly look at some characteristics of these models.

Slide 3 off

To put the project more clearly into perspective, it is important that we should know something about the force structuring process as it is accomplished at the Concepts Analysis Agency.

Slide 4

There are several models (strategic lift, warfighting analysis and support force roundout) that necessarily interact. The subordinate role of FASTALS in the system is a direct reflection of its function as a requirements model. In a nutshell, FASTALS is designed to identify a requirement for whatever support forces the combat force needs to conduct the war. The logistical limits on the war, established before the war begins, heretofore have been only marginally related to the capability of the support force.

Slide 4 off

To complicate the problem of identifying the required support force, certain support requirements, inherent to the support needs of the combat force, were not being considered by the support force roundout model--specifically combat damage. Having reached the rather startling conclusion that combat damage was being inadvertantly ignored in the structuring of the theater maintenance force, in February of this year we undertook to describe combat damage as an additional theater workload and then to use the capability of the theater support force to limit CEM's ability to repair combat vehicles. Our objective was to develop a fix that would be ready in time for the force structuring process that was to begin in June of this year. If fate would have it that we needed more than five months to complete the fix, we knew the results of our efforts would not bear on the Army force structuring process until June of 1978. Before we get too deeply into the matter of combat damage, however, let us digress for a minute to look at the two key models.

Slide 5

Our dicussions will focus on the relationships that should exist between the logistic summary and the logistic input.

Slide 6

Resource status files are the means by which CEM keeps track of its logistics situation--we have a particular interest in the Major Item Files.

Slide 7

Major items are made available to the combat force either as replacements or as an output of the theater maintenance system. In the CEM, only tanks, APCs and helicopters are repaired. There was no mechanism to vary the capability of the CEM maintenance system once the war had begun.

Slide 8

There are four types of equipment losses reported by CEM. The percent of equipment by category (tank, APC or helicopter) that falls into each of those four types of losses is established by vulnerability studies and were a "given" as far as this project was concerned. While there was no flexibility, over time, in the CEM maintenance cycle, CEM did permit a maintenance queue to develop and could accept a delay in return of the repaired equipment to the combat force in increments of four days (a theater cycle).

Slide Off

While there is certainly more to know about CEM, it is best that we take a similarly brief look at FASTALS at this time.

Slide 9

Slide 10

FPIS stands for Force Planning Information System, a Management Systems Support Agency product. The maintenance requirements data published in the FPIS file is, in fact, a statement of MACRIT data which itself is an extensive compilation of the maintenance skills required to maintain the equipment organic to every US TOE.

Slide 11

FASTALS requires this kind of information for every unit in the force. FASTALS maintenance requirements are extracted directly from the data periodically published as part of the Force Planning Information System.

Slide 12

In the numerical sequence shown, FASTALS computes the support force that is required for each region of the theater and iterates until it reaches a stable, time phased force deployment troop list incremented at 10-day intervals for the duration of the theater war.

Slide 13

In very general terms, then, this is the relationship that existed between CEM and FASTALS before we embarked on the project. Communication between the models was a one-way street. While CEM, in its system of reports, was telling force planners what and how much equipment was combat damaged, FASTALS was unable to deal with that knowledge, being forced to rely on FPIS for a statement of the maintenance requirement. And, of great concern to many, the models did not consider the capability of the support force in the equation of theater combat power.

Slide 14

These findings led us to the conclusion that combat damage, as a product of the war, had to be considered, measured, and addressed. There were some questions that we knew would have to be answered, however, before we could integrate the models.

Slide 15

Even if we could find a manageable definition of combat damage there were other questions to be answered, and we knew that some model modification would be required.

Slide 16

The team was a low profile gathering of concerned analysts. There was no structure; we were only loosely knit, if knit at all. We gave each other encouragement, advice and, as appropriate, compassion. We were strong on creative expression and light on formality. In fact, we sought to avoid attention for fear that we might lose control to a more formalized statement of our project, its institutionalization and the inevitable cost in time.

Slide 17

In that we thought it necessary to define combat damage in terms of man-hours to repair, there were some statements of doctrine and assumptions that had to be made.

Slide 18

In concept definition we had to identify this echelon at which certain levels of damage would be addressed, and we had to know, for queuing purposes, the amount of maintenance backlog that was to be permitted by theater policy. Finally, we chose not to look at the capability of various maintenance-related MOSs but rather at the unit capability as expressed in Section I of each maintenance TOE.

Slide 19

Several times now we have made reference to CODAM--the Ordnance and Chemical Center and School's Combat Damage Assessment Model. The team found CODAM to be the most reliable, immediately available expression of the time required to repair a combat damaged tank. While the CODAM statement of repair times was subjective, the times were the best opinions of experienced NCOs and Warrant Officers who were thoroughly prepared, by recent and controlled exposure to actual combat damage, to render an expert opinion. Those expert opinions were considered in conjunction with opinions of professionals assigned to the Ordnance and Chemical Center and School, and ultimately became a data input to this combat damage assessment model. Our efforts to validate the CODAM product with empirical data and with advanced model results available at BRL were intuitively satisfying but never pursued to a formal conclusion. Subsequent decisions, however, by a DA, DCSLOG team studying combat essential repair parts requirements, happily have substantiated our confidence in CODAM.

Slide 20

The lower half of this portrayal of the CODAM distribution represents CODAM output data, stratified into levels of maintenance as established and defined earlier in this presentation. The expected value of 550 maintenance man-hours for the average depot maintenance job is a comfortable expression of a battlefield kill--a repair task that would not be undertaken within the corps. As such it approaches, percentage-wise, the vulnerability analyses that traditionally have been employed in warfighting simulations at CAA. In this regard, then, the CODAM distribution left us with a certain sense of "being in the ballpark". The upper half of this slide is the result of our conversion of CODAM full spectrum

damage into the direct support and general support maintenance workloads that were to be subsequently addressed in our team's capability analysis. Using CODAM data, we were able to say that 76 pecent of the tanks that sustained a single hit on the battlefield would require an average of 14 man-hours of direct support maintenance, and that 24 percent would require 69 man-hours of general support maintenance.

Slide 21

In an attempt to reconcile several emerging theater maintenance concepts, we made two changes to what had been previously portrayed, in CAA models, as doctrine. Neither modification was expected to cause any substantial difficulties for force planners who might choose to act on the results of our force structuring recommendations. The first, and perhaps most radical departure, was the introduction of a Battle Damage Contact Team (TOE 29-610 series) that was designed to respond to the FM 100-5 call to "support forward". The Battle Damage Contact Team would be present throughout the combat zone to deal with the direct support portions of combat damage and with normal maintenance tasks that were beyond the capacity of the divisional and nondivisional direct support units. The other change was the introduction of a means to model the pool of repairable equipment that is representative of the backlog known to be essential to general support maintenance operations.

Slide 22

A modification to FASTALS logic was required to allow the introduction of CODAM generated maintenance requirements. Once embodied as a part of the FASTALS workload no other changes were required, short of a brief manual conversion of theater maintenance capability into an expression of the number of combat vehicles produced by the theater maintenance facility. The conversion process became principally a bookkeeping exercise. In general, a portion of the man-hours available in the theater's maintenance units were counted and allocated against the requirement to repair the combat damage that was reported by CEM. The result was the number of combat vehicles capable of being repaired by each maintenance unit.

Slide 23

The process of allocating unit maintenance capability to a varying mix of tanks and APCs is shown here.

Slide 24

This process depicts our technique for fencing unit capability for the repair of noncombat vehicles such as trucks. The example shown here is indicative of a fictitious theater commander's desire to use 60 percent of the maintenance man-hours available to this company to repair tanks and APCs.

Slide 25

To attenuate a maintenance unit's capability during its first few days in the theater we reduced the design capability line to some percentage

less than 100. In this case an armored division maintenance battalion is capable of repairing, during its initial four days in the theater, the combat damage that is sustained by 75 tanks and 121 APCs. The damage addressed by this divisional maintenance battalion, we must recall, is by definition direct support and is relatively light, requiring only 14 maintenance man-hours per tank. The time to repair APCs was subjectively determined based on empirical data that was assembled into a distribution similar to that of CODAM. It is set at 12 man-hours of direct support maintenance per APC.

Slide 26

Data shown here is for a nondivisional direct support maintenance company (forward); one that by doctrine, for example, supports an armored cavalry regiment in an area support role.

Slide 27

This is a general support maintenance company. Its four-day capability is considerably less than that of the direct support companies because the damage it repairs is far more extensive--69 vs 14 maintenance man-hours per tank.

Slide 27 off

The quantities of repaired vehicles we've been talking about here, when multiplied by the number of maintenance units available in the theater, became the maximum, time-phased output of the CEM maintenance facility.

Slide 28

If you recall, the CEM maintenance facility could not accomodate a variable capacity statement, nor could it accept a statement of maintenance capacity for US tanks that was different from that for NATO tanks. In other words, once set in the model the CEM maintenance facility would repair a certain number of tanks for each of 12 types from D-day to war's end, given that the repairable asset was in the maintenance queue. It was essential that some flexibility be built into the CEM to capitalize on our now more comprehensive and accurate statement of theater maintenance capability.

Slide 29

The new CEM maintenance facility consists of three partitions (US, FRG, and other NATO, for example) with a separate facility for each category of equipment (tank, APC, helicopter) within each partition. Each facility operates with a queue and a transportation delay, and the percent output of each facility matches the input percentage by equipment type. In this way we have established a means to roughly approximate a theater maintenance priority system.

Slide 29 off

Having defined combat damage, and modified both the warfighting model and the theater support force roundout model, we were now capable of introducing the variable maintenance capability and measuring its effect on the warfighting analysis.

Slide 30

Shown here are two representations of tank losses sustained during recent simulations at the Concepts Analysis Agency. The actual numbers are not important and have been deleted from this slide. What is important is that in the early days of the war, simulated in our models, there is a large number of damaged tanks. There is an incentive to repair these tanks and return them to the combat elements on an expedited basis, especially since they are heavily weighted contributors to the firepower of the theater force. The period of high losses, however, occurs exactly at that time when one would expect the US to have its least capability to repair is damaged equipment. It is important then, that decision makers not be misled by an overstatement of our repair capability. In the past, force planners did not have the tools with which to vary the repair capability of the theater maintenance force. And understandably, in an effort to portray an "average" capability over the course of the simulated war, the capability in the early days of the war was overstated. This overstatement was directly translated into a "greater-than-real" availability of combat vehicles with an attendant relatively high intensity of the warfighting analysis. That high intensity carried with it a high ammunition rate and comparably high rates of personnel and equipment losses, especially during the early days of the simulated war.

Slide 31

The maintenance capability that was attributed to the US forces in the European theater for a recent study is shown here. The theater maintenance capabilities of 1650 US tanks and 1768 US APCs are not at all unreasonable for a mature theater, but it is our opinion that the model shortcomings we have been discussing forced model operators to misrepresent the theater capability in the early days of the simulated war. What is not apparent on this slide is the fact that every NATO tank and every NATO APC was being repaired at the same rate; there was no way to tailor the capability of the theater's maintenance facilities to reflect a difference in national preparedness or fundamental capability.

Slide 32

The red lines indicate the capabilities that are now being portrayed in the CEM. Different capabilities are being employed for non-US NATO forces. And as one can see, the US capability logically grows as US forces arrive and settle into the theater. In that the theater is no longer able, in the wink of an eye, to repair its battle damaged combat vehicles, the intensity and overall tone of the simulated war has changed. And that is as it should be. If we can control the inputs to our simulation models, we should expect to find the models willing to respond to the factors we use to simulate reality.

Slide 33

The title of this presentation is "Combat Damage - A Factor of Significance in Theater Army Force Structuring". This chart portrays the significance of combat damage in the force structuring process at the Concepts Analysis Agency. Not only has a new workload been introduced into the force structuring process, however. The undertaking of the project prompted a doctrinal review and thorough scrub of maintenance unit allocation rules with the following effect on the composition of the maintenance force in the several corps of a recent theater simulation at the Concepts Analysis Agency.

Slide 34

This reduction has been accomplished while providing a more timely, more complete maintenance service to the corps commander.

Slide 35

No study would be complete without an assessment of its shortcomings.

Slide 36

On the other hand the five months that were rather frantically spent in pursuit of our objective appear to have been worth the investment.

Slide 36 off

The team that rose to the challenge of this task is responsible for the benefits it brings to the force structuring process. There are some known shortcomings in the methodology and, I'm sure, some that have not yet been discovered. I'll gladly take credit for them, and respond positively to any constructive criticism you may like to express at this time.

COMBAT
DAMAGE

COMBAT
DAMAGE

COMBAT
DAMAGE

A FACTOR OF SIGNIFICANCE IN THEATER ARMY FORCE STRUCTURING

COMBAT
DAMAGE

COMBAT
DAMAGE

OBJECTIVE

LINK A WARFIGHTING MODEL TO A FORCE ROUNDOUT MODEL SO THAT THEATER CAPABILITY TO REPAIR COMBAT VEHICLES CAN BE USED TO DESCRIBE THE AVAILABILITY OF REPAIRED COMBAT VEHICLES (AN INPUT REQUIRED BY THE WARFIGHTING MODEL)

PRESENTATION OUTLINE

I CEM DESIGN: FASTALS DESIGN

II INCENTIVE TO LOGISTICALLY LINK CEM AND FASTALS

III COMMUNITY INVOLVED

IV ASSUMPTIONS/POLICY/DEFINITION

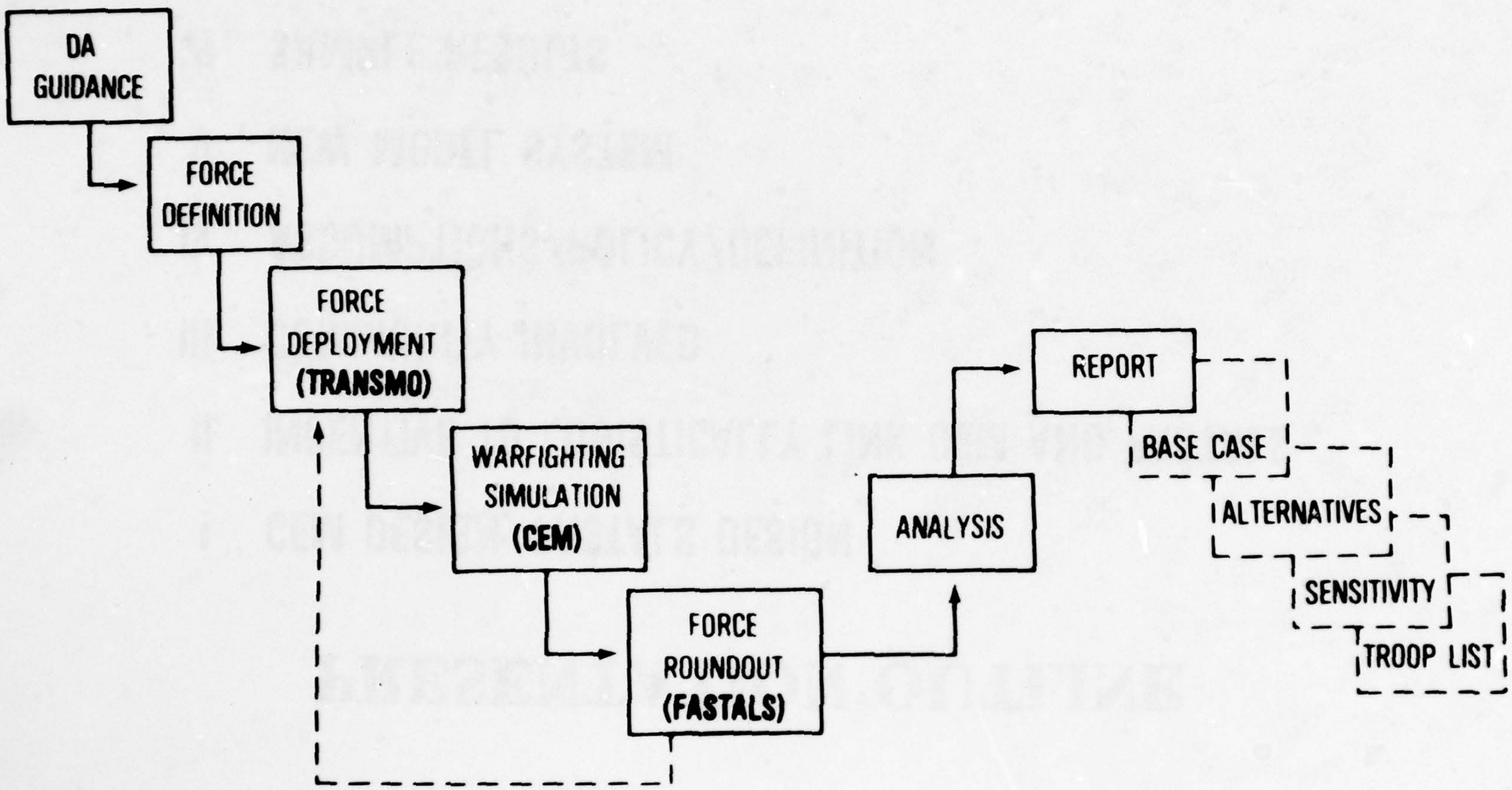
V NEW MODEL SYSTEM

VI SAMPLE RESULTS

VII SHORTCOMINGS

VIII EXPANSION/SPIN-OFFS

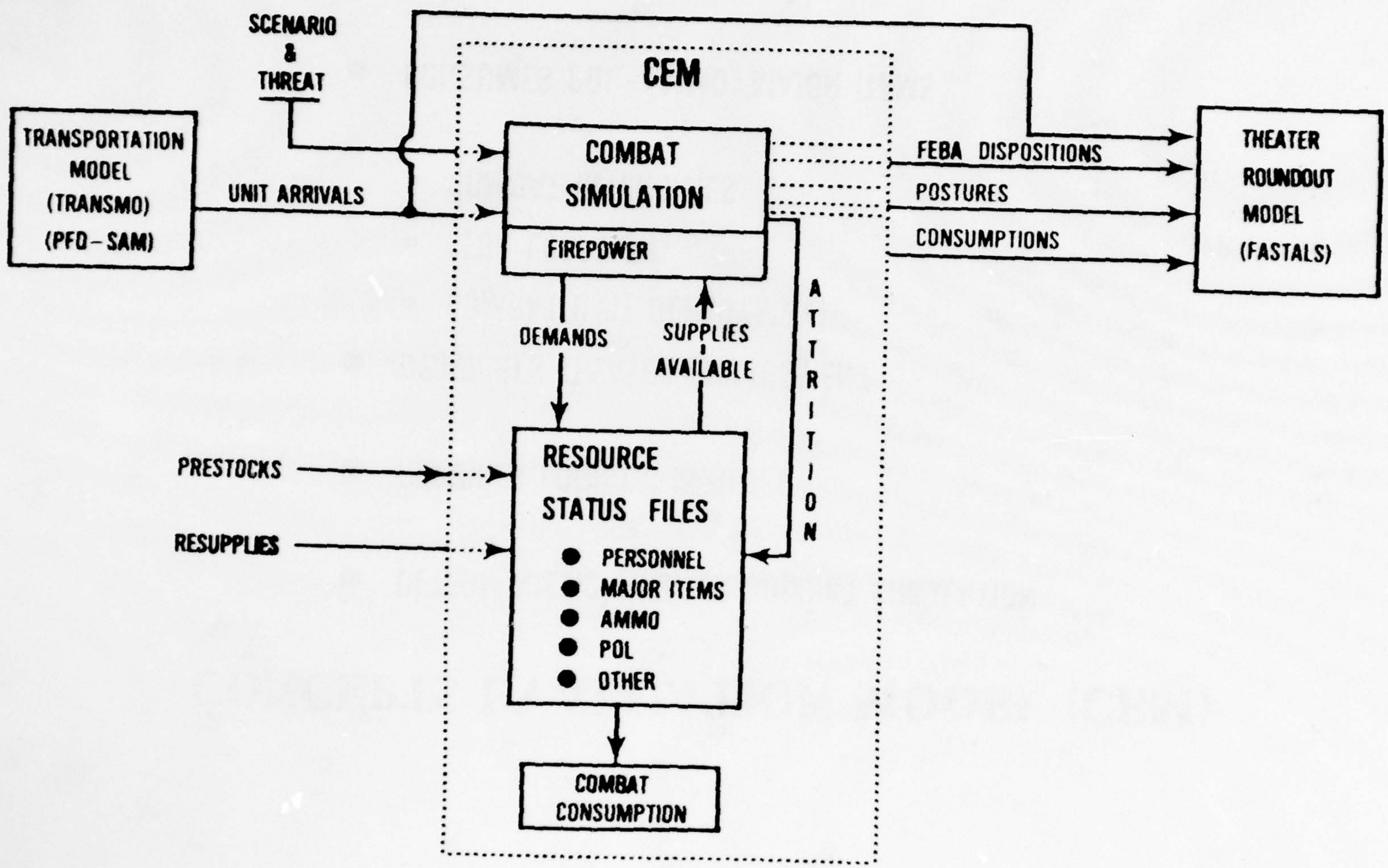
FORCE STUDY METHODOLOGY



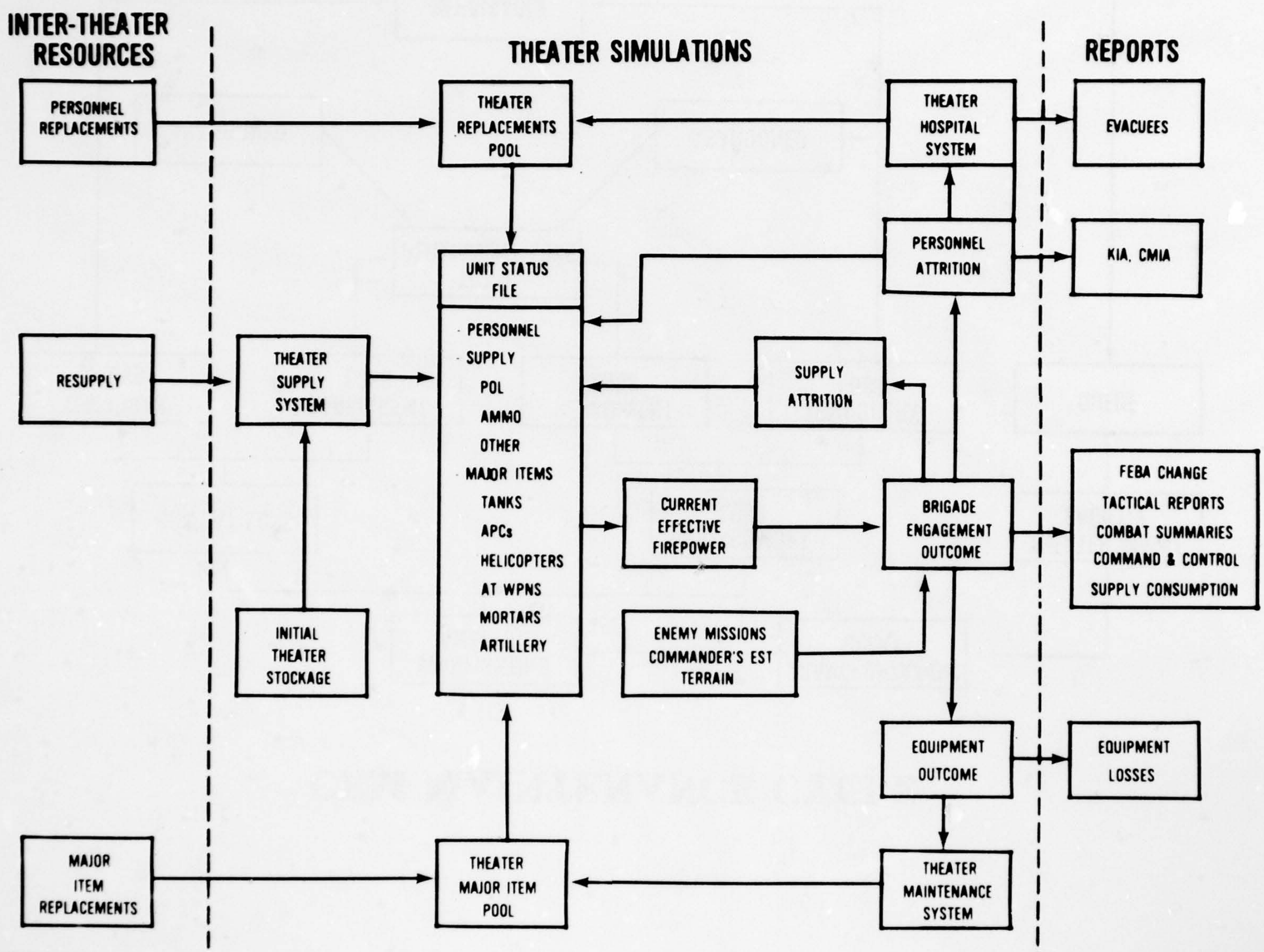
CONCEPTS EVALUATION MODEL (CEM)

- DETERMINISTIC THEATER COMBAT SIMULATION
- REQUIRES LOGISTIC INPUT
- DESCRIBES THEATER ENGAGEMENT
  - COMBAT UNIT DEPLOYMENT
  - FEBA LOCATION
  - COMBAT INTENSITIES
- CONSUMES POL, AMMO, MAJOR ITEMS
- PRODUCES LOGISTIC SUMMARY

CEM WARFIGHTING SIMULATION



RESOURCE FLOWS



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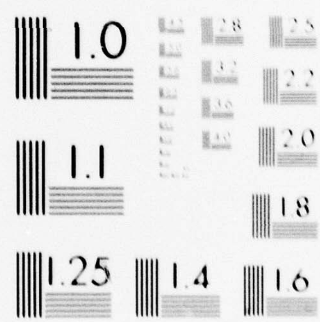
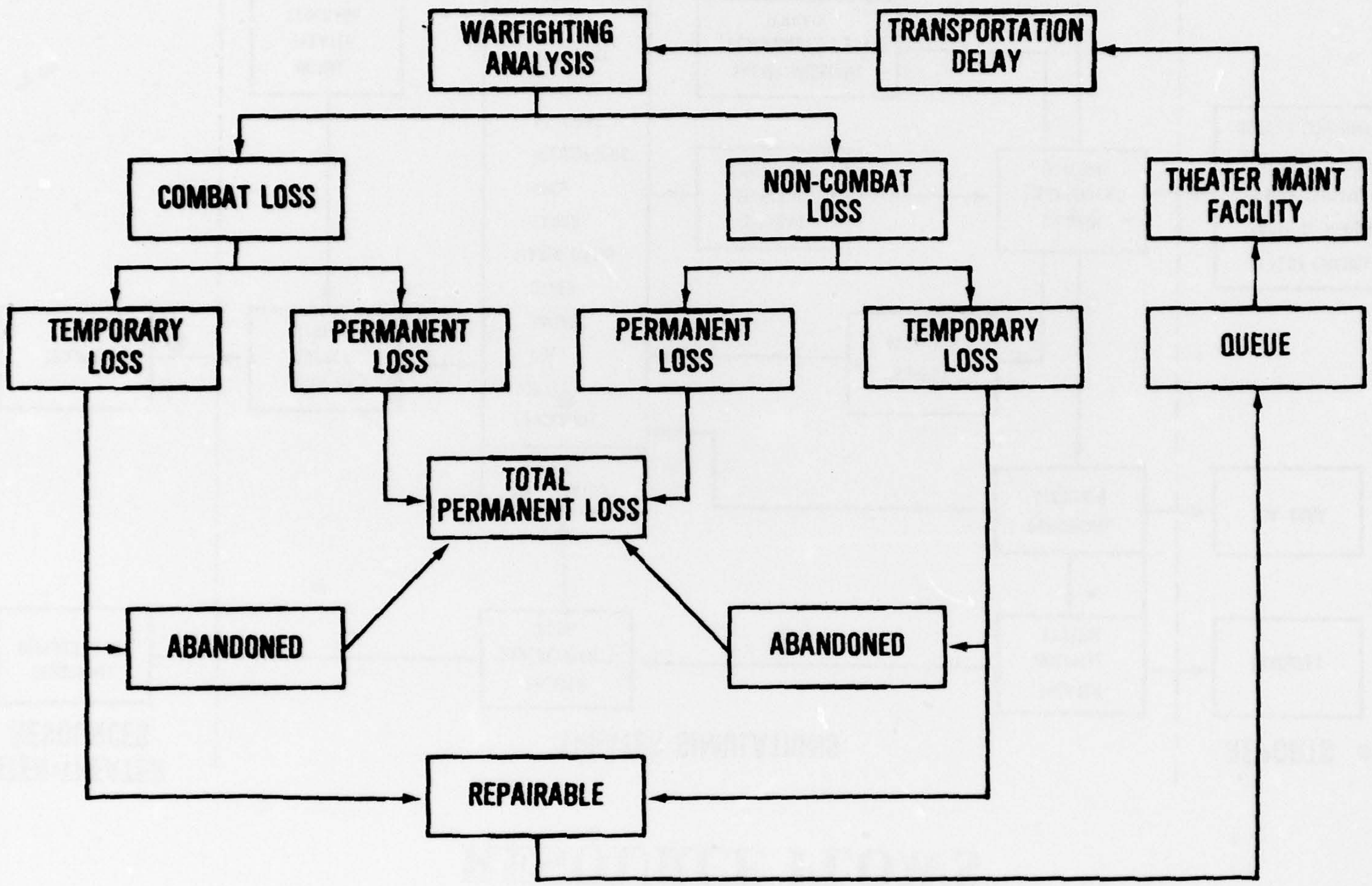


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CEM MAINTENANCE CYCLE



FASTALS

FORCE

ANALYSIS

SIMULATION OF

THEATER

ADMINISTRATIVE &

LOGISTIC

SUPPORT

FASTALS

- REQUIREMENTS MODEL
- RESPONDS TO CEM CONSUMPTION
- ACCUMULATES WORKLOAD (FPIS)
- RECOGNIZES ORGANIZATIONAL RELATIONSHIPS
- ALLOCATES SUPPORT STRUCTURE
- ITERATES TO STABLE CONDITION

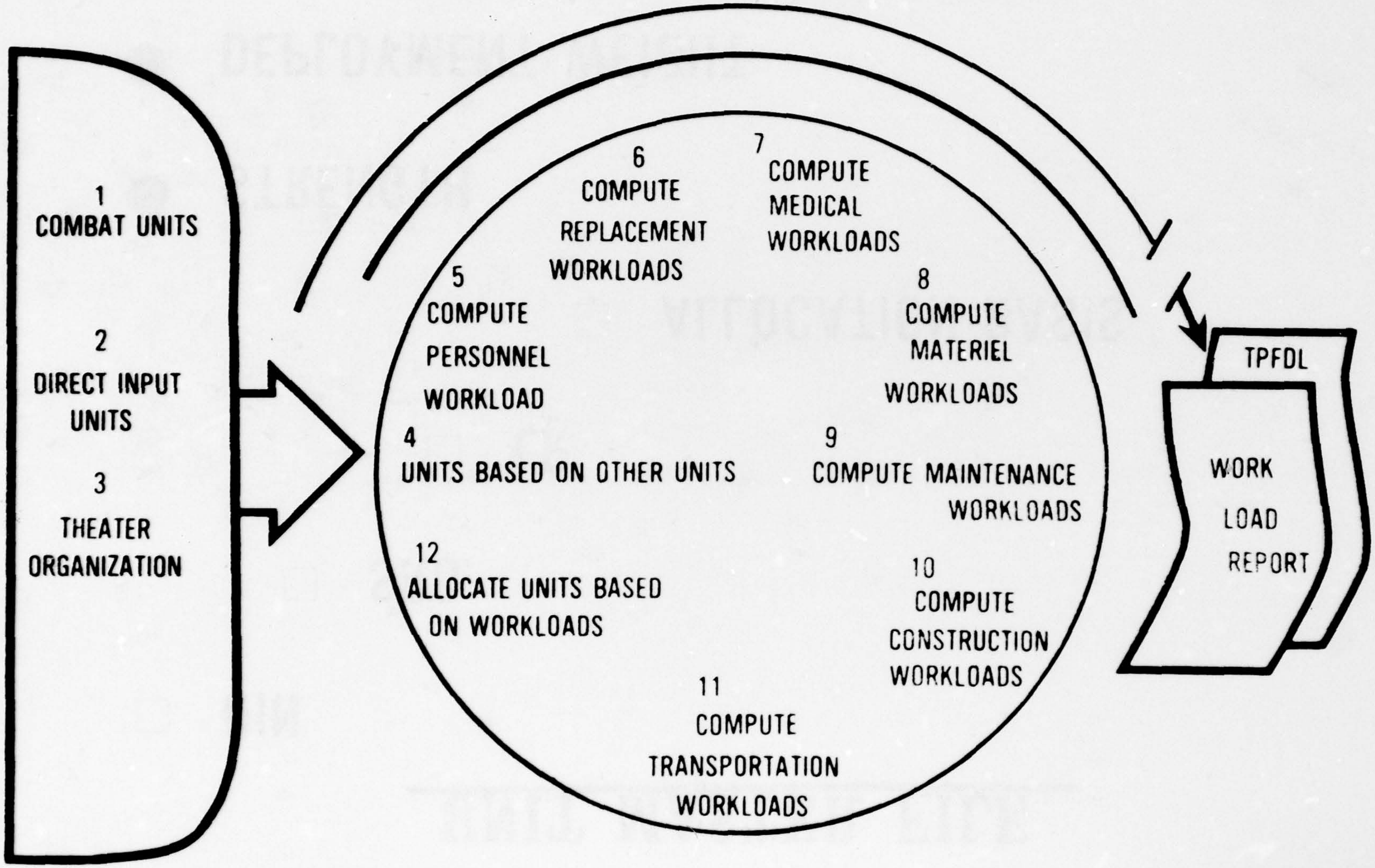
UNIT MASTER FILE

- ☐ UIN
  - ☐ SRC
    - ☐ LR
      - ☐ ALLOCATION BASIS

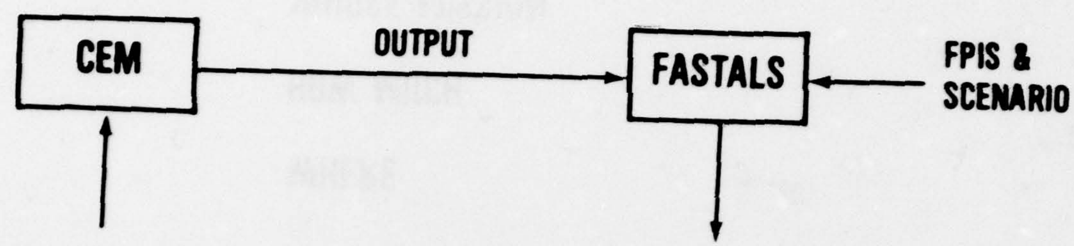
- STRENGTH
- DEPLOYMENT WEIGHT
- MAINTENANCE REQUIREMENTS

APRIL 1971

FASTALS LOGIC FLOW



MODEL SYSTEM



- COMBAT FORCES
- LOG FACTORS
- GAMES RULES

- BALANCED
  FORCE STRUCTURE

COMBAT DAMAGE

WHERE

HOW MUCH

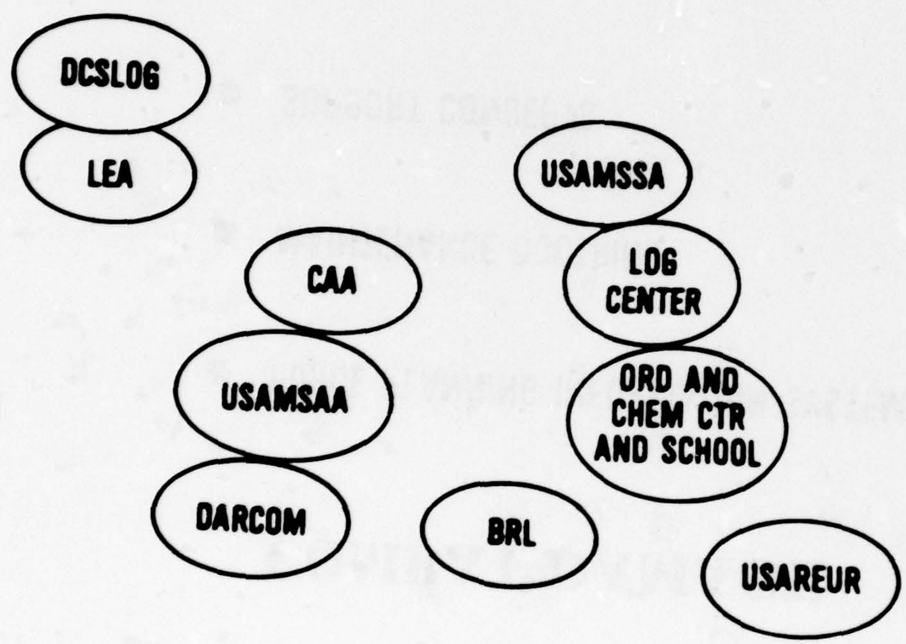
WHOSE MISSION

WITHIN SUPPORT CAPABILITY

COMBAT DAMAGE

- FORCE PLANNING INFORMATION SYSTEM
- MAINTENANCE DOCTRINE
- SUPPORT CONCEPTS
- THEATER POLICY
- MODEL DEFINITION OF COMBAT DAMAGE
- "REQUIREMENTS" MODEL

THE TEAM



DCSLOG
LEA
CAA
USAMSAA
DARCOM
USAMSSA
LOG CENTER
ORD AND CHEM CTR AND SCHOOL
BRL
USAREUR

ASSUMPTIONS (TANK - AUTO MAINTENANCE)

- GS BACKS UP DIVISIONAL AND NON DIVISIONAL DS UNITS (CAPACITY)
- GS SUPPORTS DIVISIONAL AND NONDIVISIONAL DS UNITS (CAPABILITY)
- 29-207 AND 29-208 ARE AREA SUPPORT (NONDIVISIONAL) UNITS:
  29-208 BACKS UP 29-207
- FPIS REPRESENTS NORMAL MAINTENANCE
- CODAM DEFINES COMBAT DAMAGE
- MAINTENANCE STANDARDS STUDY DEFINES NON-COMBAT DAMAGE
- C3FE STUDY DEFINES MAINTENANCE CYCLE TIMES

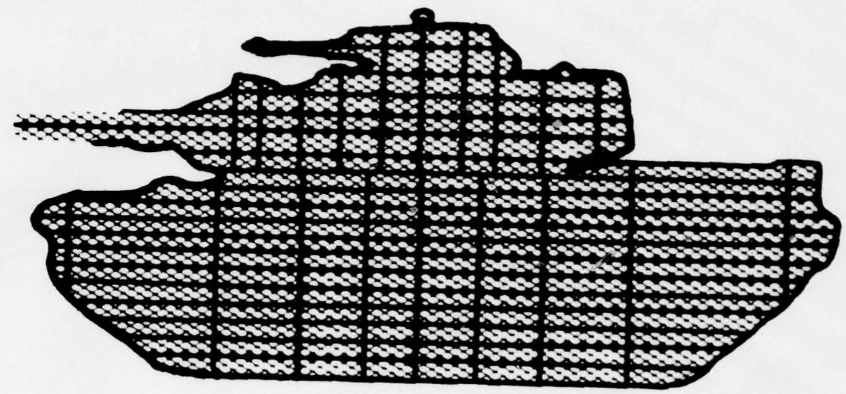
POLICY/DEFINITIONS

- DAMAGE REQUIRING $\geq$ 48 MAINT MAN HRS = GS
- DAMAGE REQUIRING $<$ 48 MAINT MAN HRS = DS
- DAMAGE REQUIRING $>$ 96 MAINT MAN HRS = NONREPAIRABLE IN CORPS

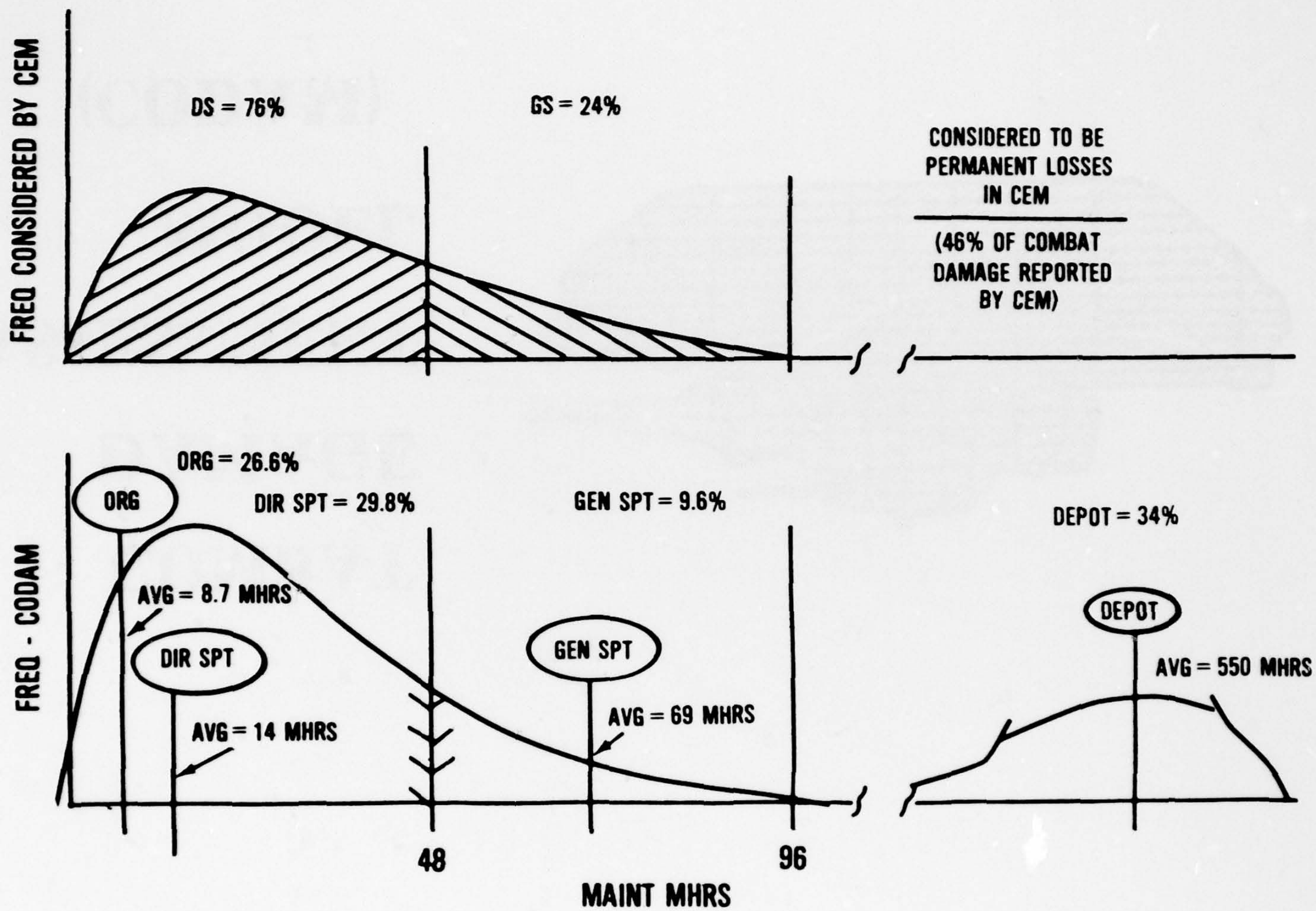
- MAX BACKLOG IN DIV MAINT BN = 2 DAYS
- MAX BACKLOG IN 29-207H = 2 DAYS
- MAX BACKLOG IN 29-208H = 4 DAYS
- NO LIMIT ON BACKLOG IN 29-137H

- UNIT CAPABILITY TO REPAIR STATED IN TOE SUMMARY

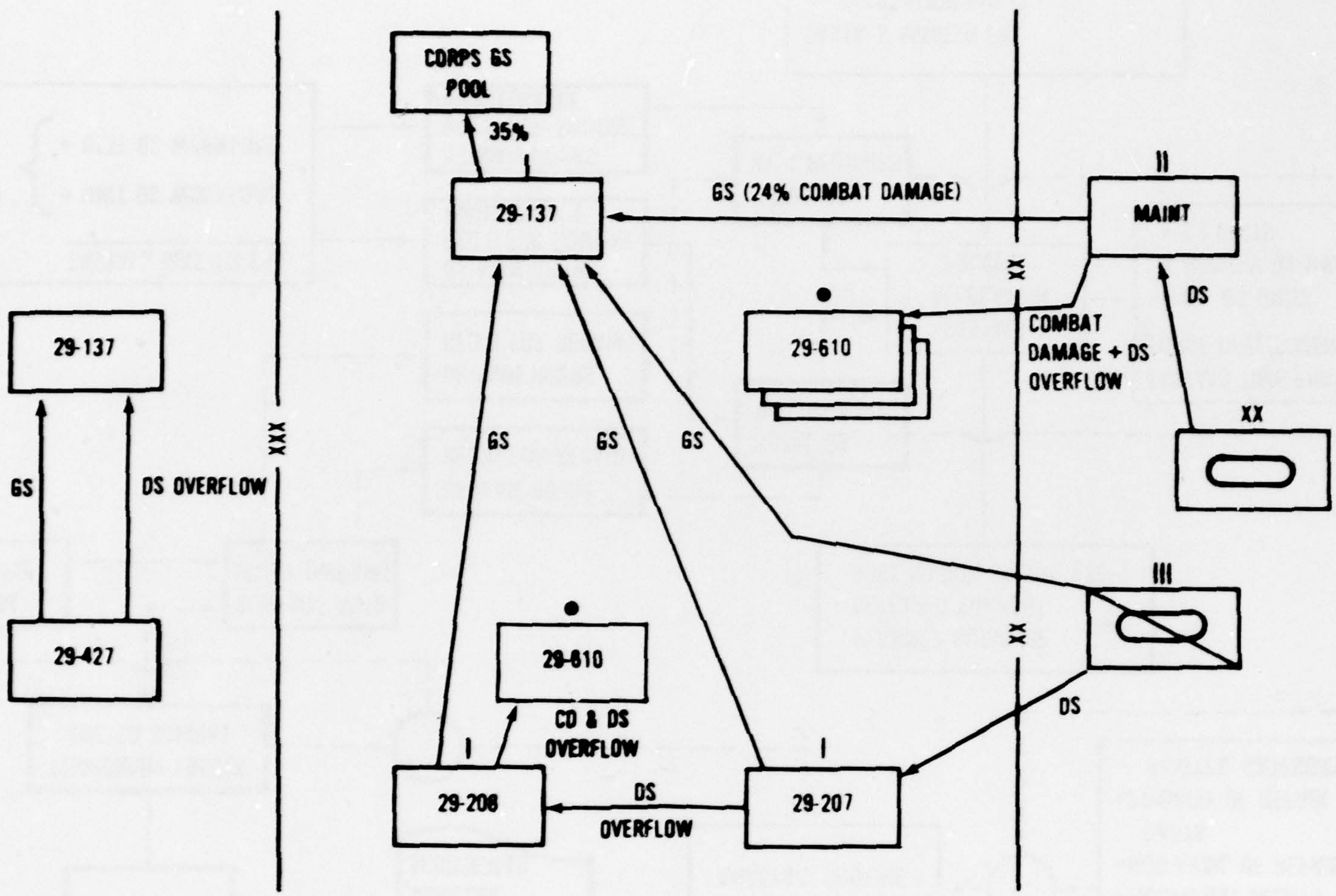
COMBAT DAMAGE ASSESSMENT MODEL (CODAM)



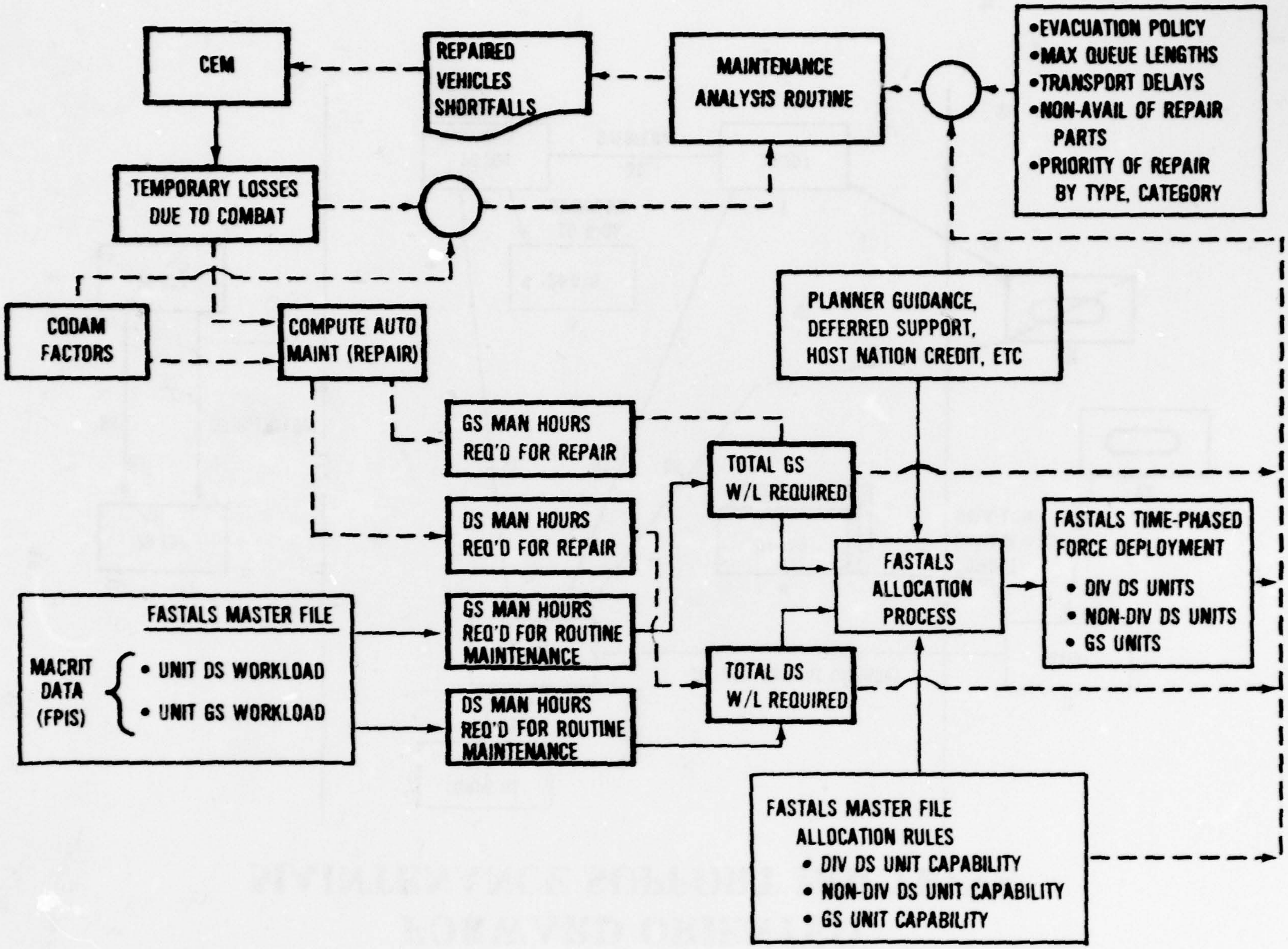
CODAM DISTRIBUTION
(M60A1 TANKS)



FORWARD ORIENTED
MAINTENANCE SUPPORT DOCTRINE



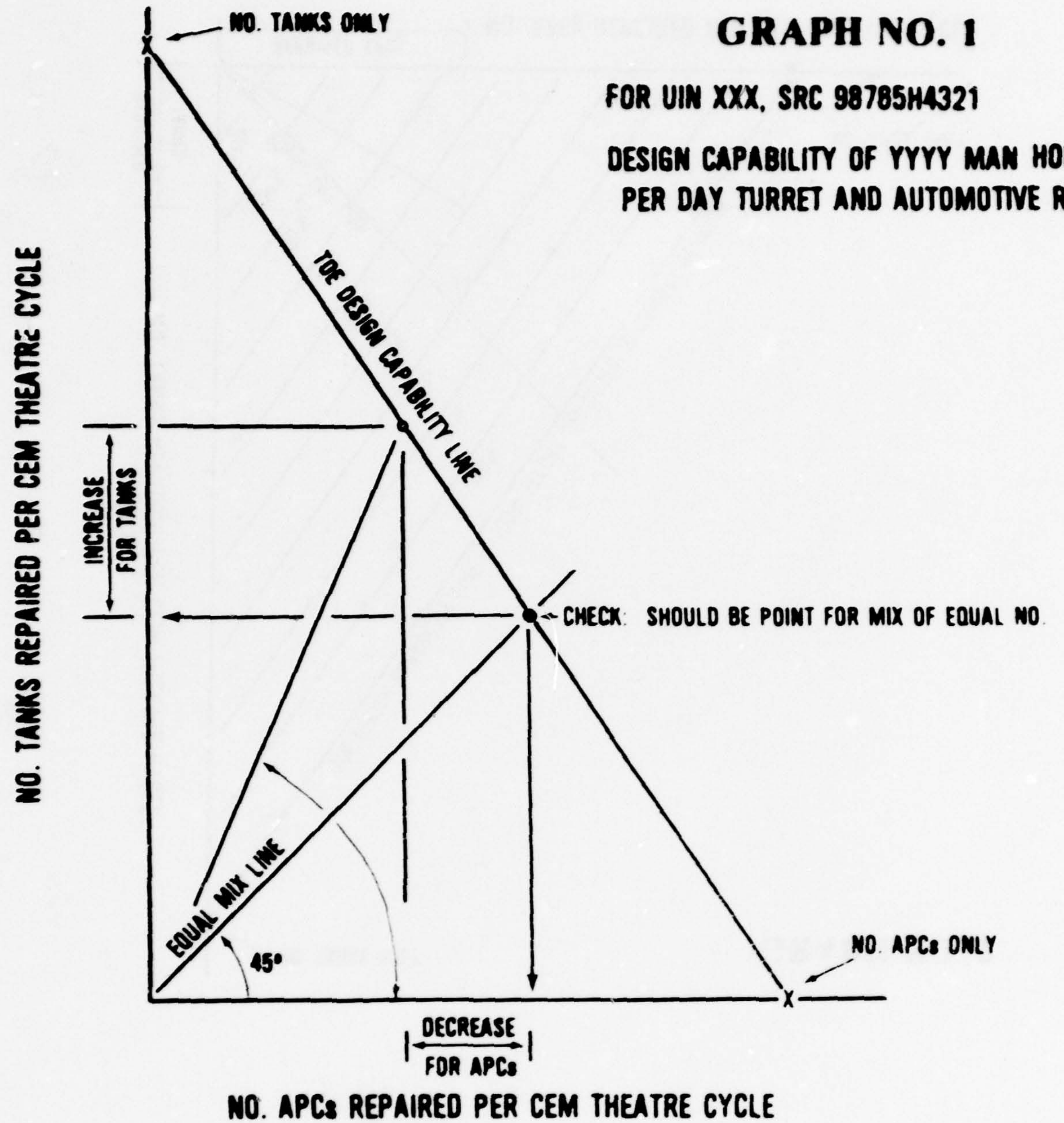
INTRODUCTION OF COMBAT DAMAGE



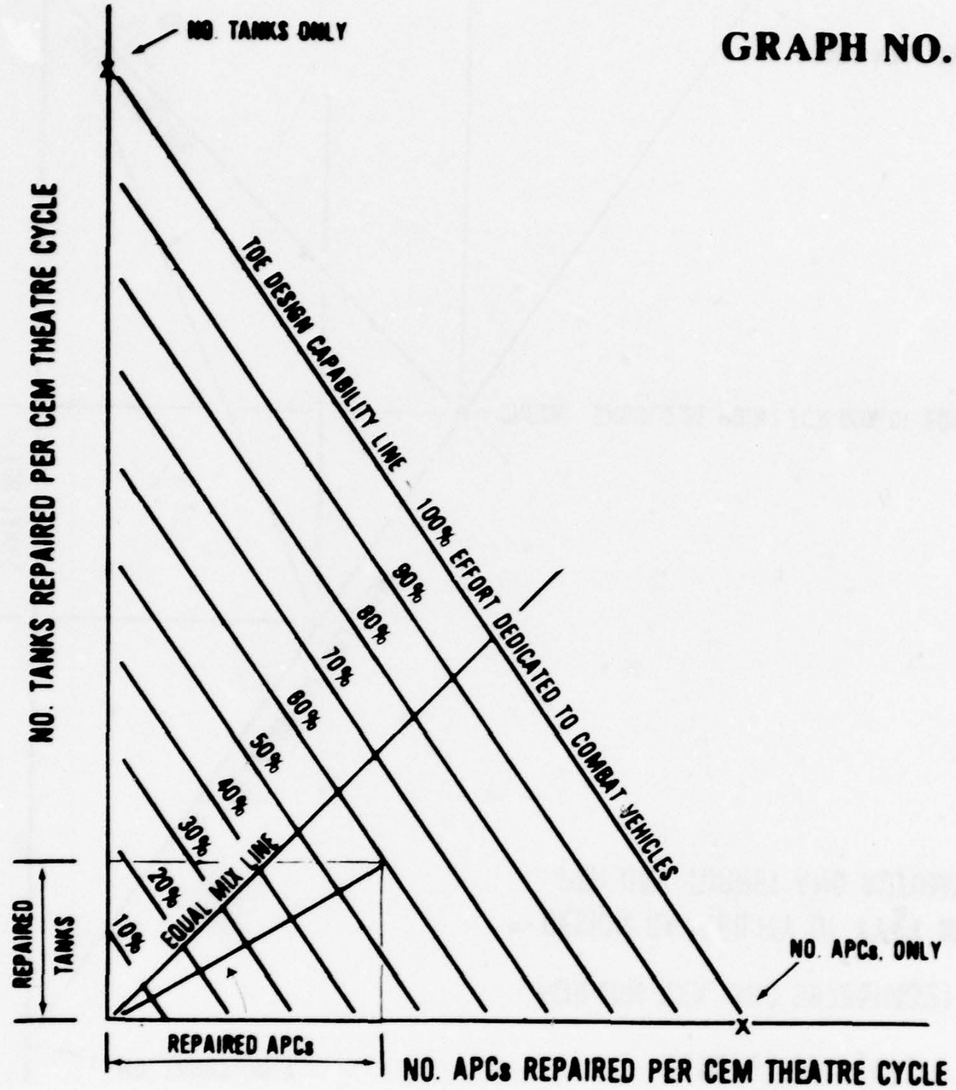
GRAPH NO. 1

FOR UIN XXX, SRC 98785H4321

DESIGN CAPABILITY OF YYYY MAN HOURS PER DAY TURRET AND AUTOMOTIVE REPAIR



GRAPH NO. 2

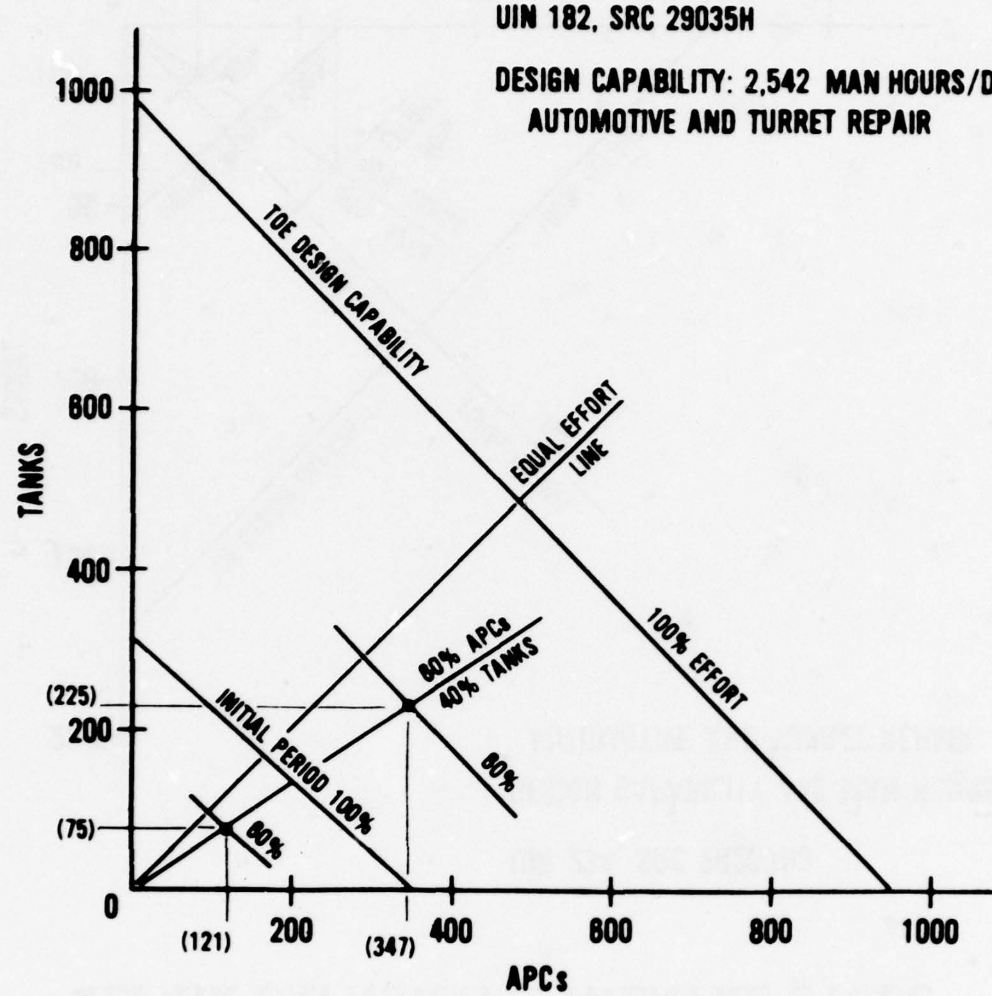


NO. TANKS ONLY
TOE DESIGN CAPABILITY LINE – 100% EFFORT DEDICATED TO COMBAT VEHICLES
90%
80%
70%
60%
50%
40%
30%
20%
10%
EQUAL MIX LINE
NO. APCs. ONLY
NO. TANKS REPAIRED PER CEM THEATRE CYCLE
REPAIRED TANKS
REPAIRED APCs
NO. APCs REPAIRED PER CEM THEATRE CYCLE

REPAIR CAPABILITY/THEATRE CYCLE

UIN 182, SRC 29035H

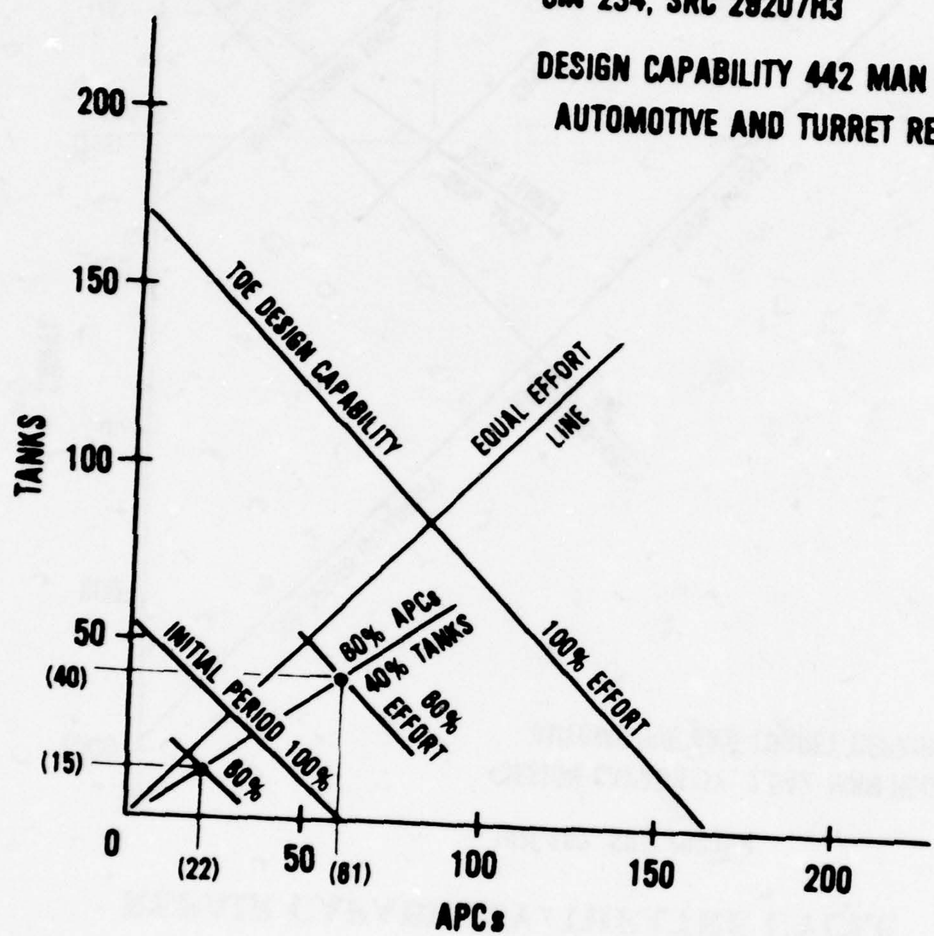
DESIGN CAPABILITY: 2,542 MAN HOURS/DAY
AUTOMOTIVE AND TURRET REPAIR



REPAIR CAPABILITY/THEATRE CYCLE

UIN 234, SRC 29207H3

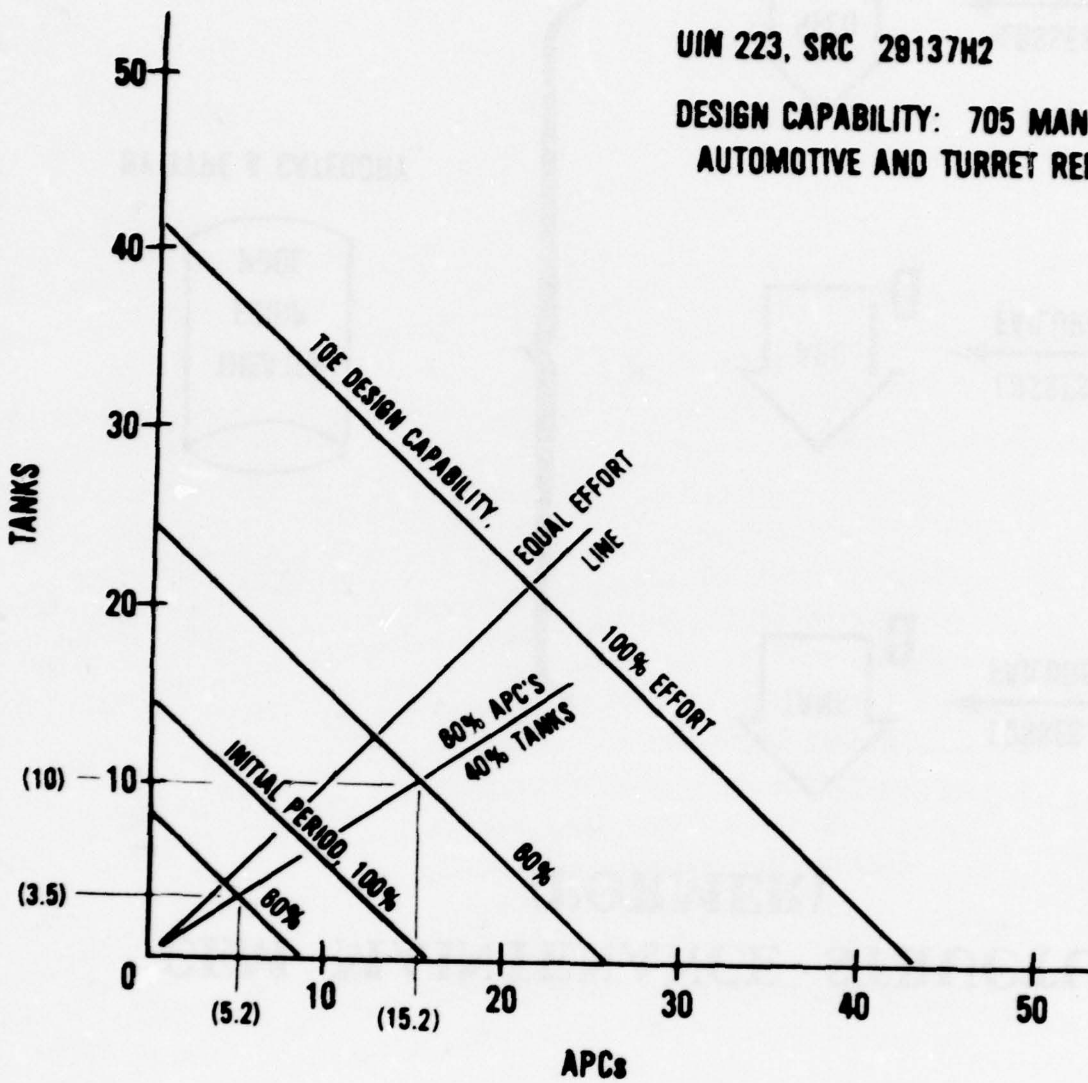
DESIGN CAPABILITY 442 MAN HOURS/DAY
AUTOMOTIVE AND TURRET REPAIR



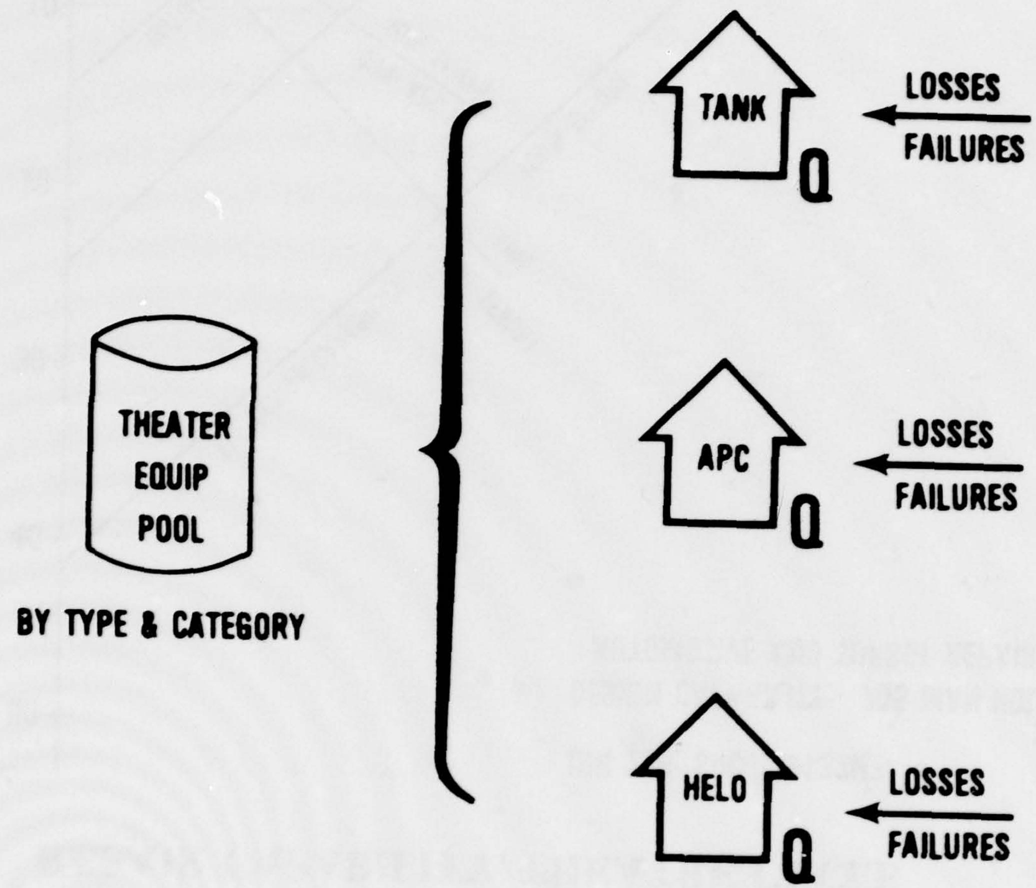
REPAIR CAPABILITY/THEATRE CYCLE

UIN 223, SRC 29137H2

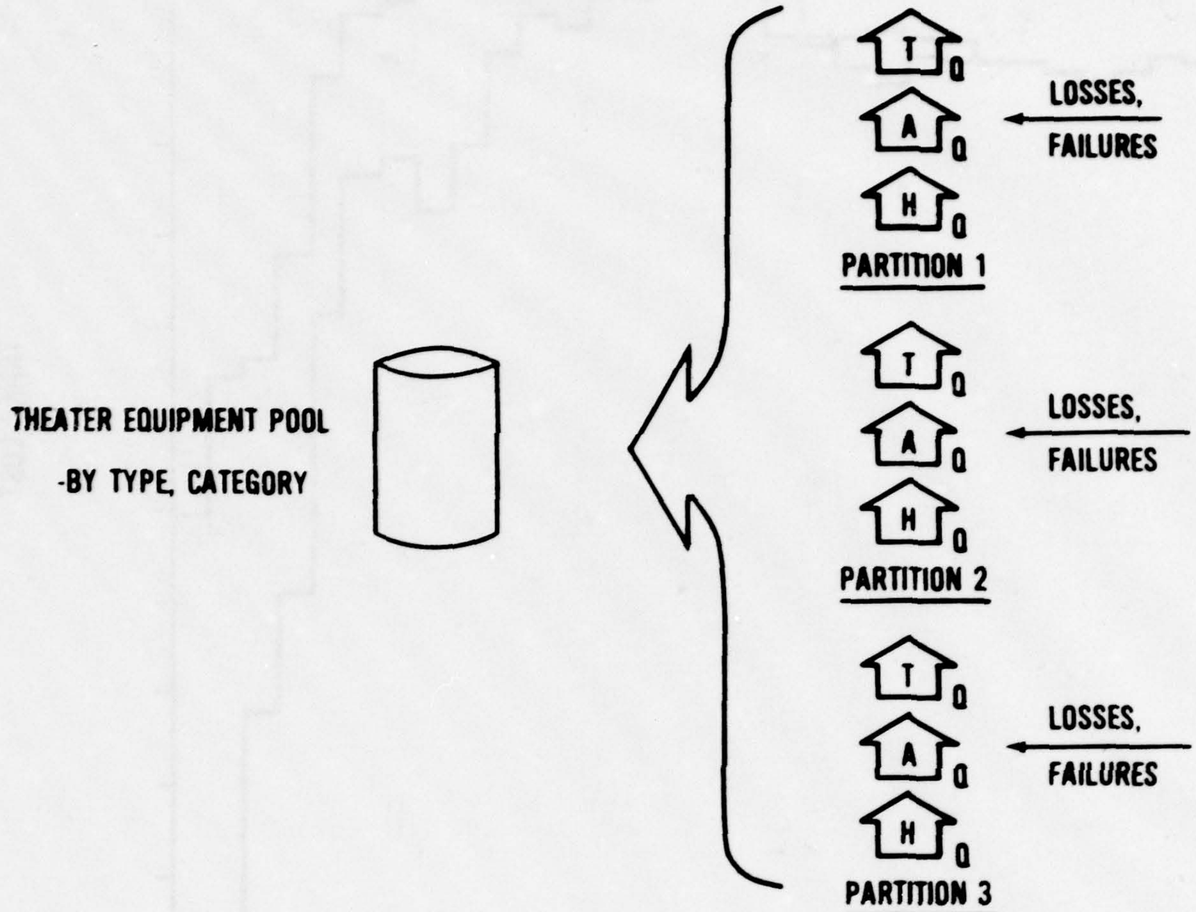
DESIGN CAPABILITY: 705 MAN HOURS/DAY AUTOMOTIVE AND TURRET REPAIR



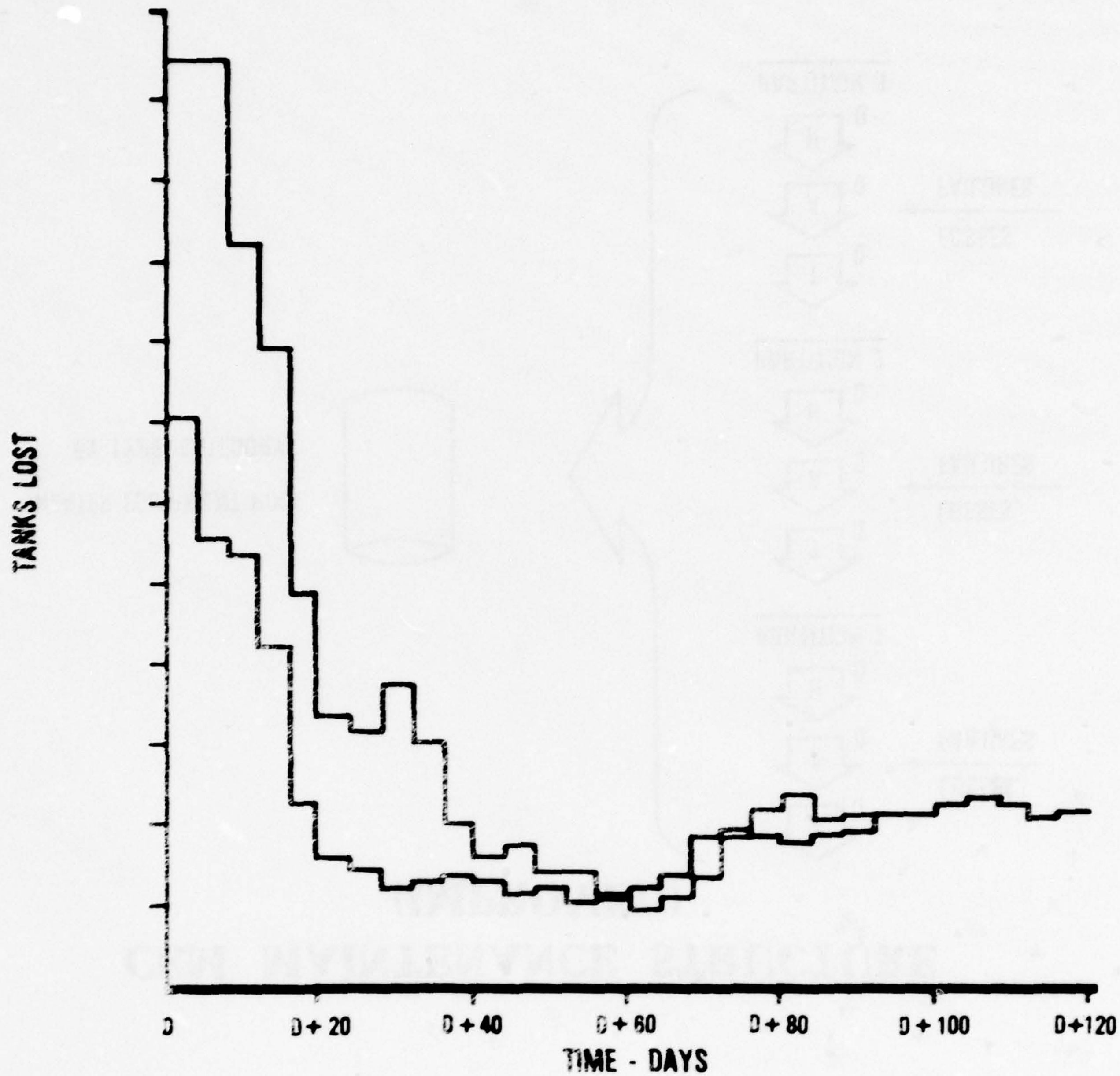
CEM MAINTENANCE STRUCTURE (FORMER)



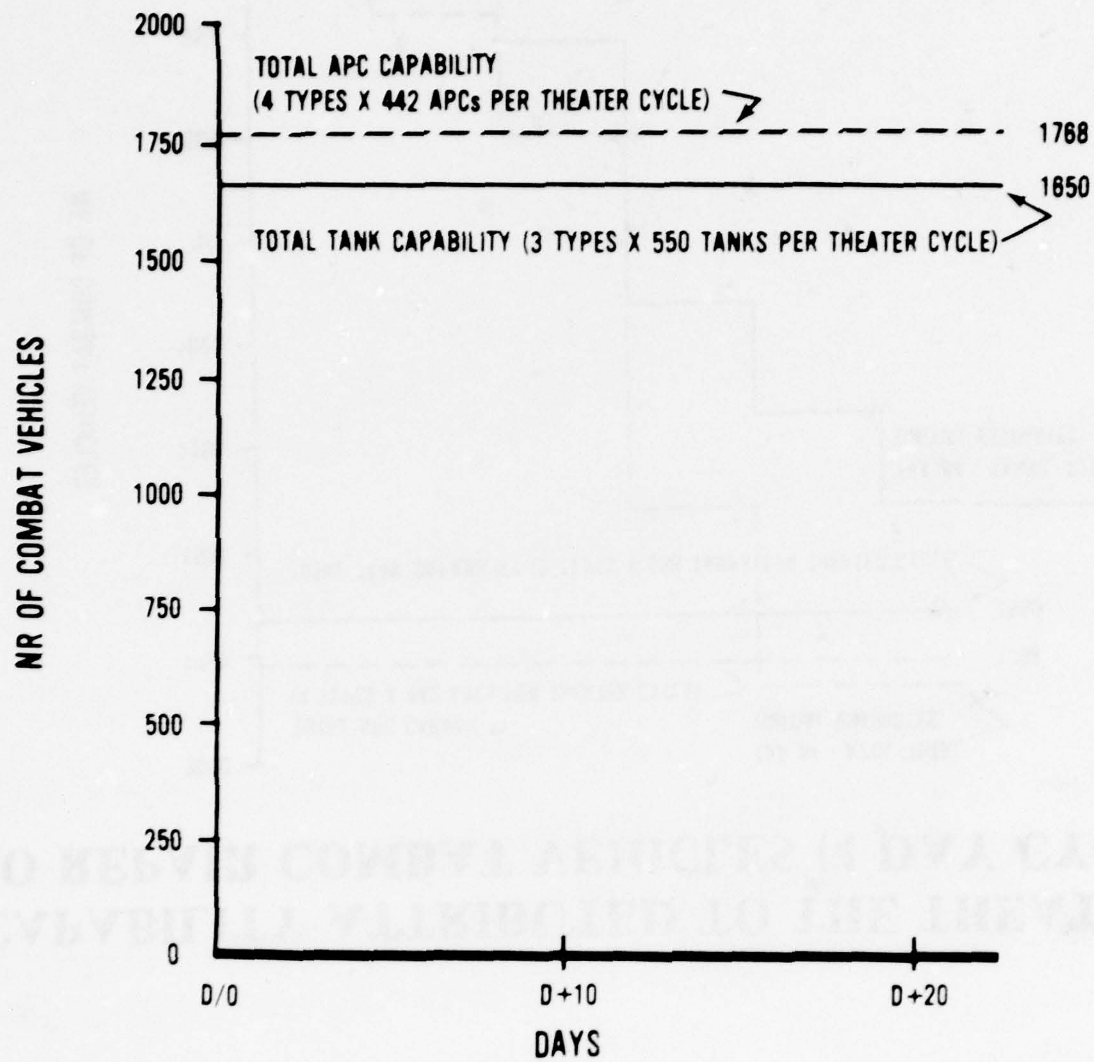
CEM MAINTENANCE STRUCTURE
(IMPROVED)



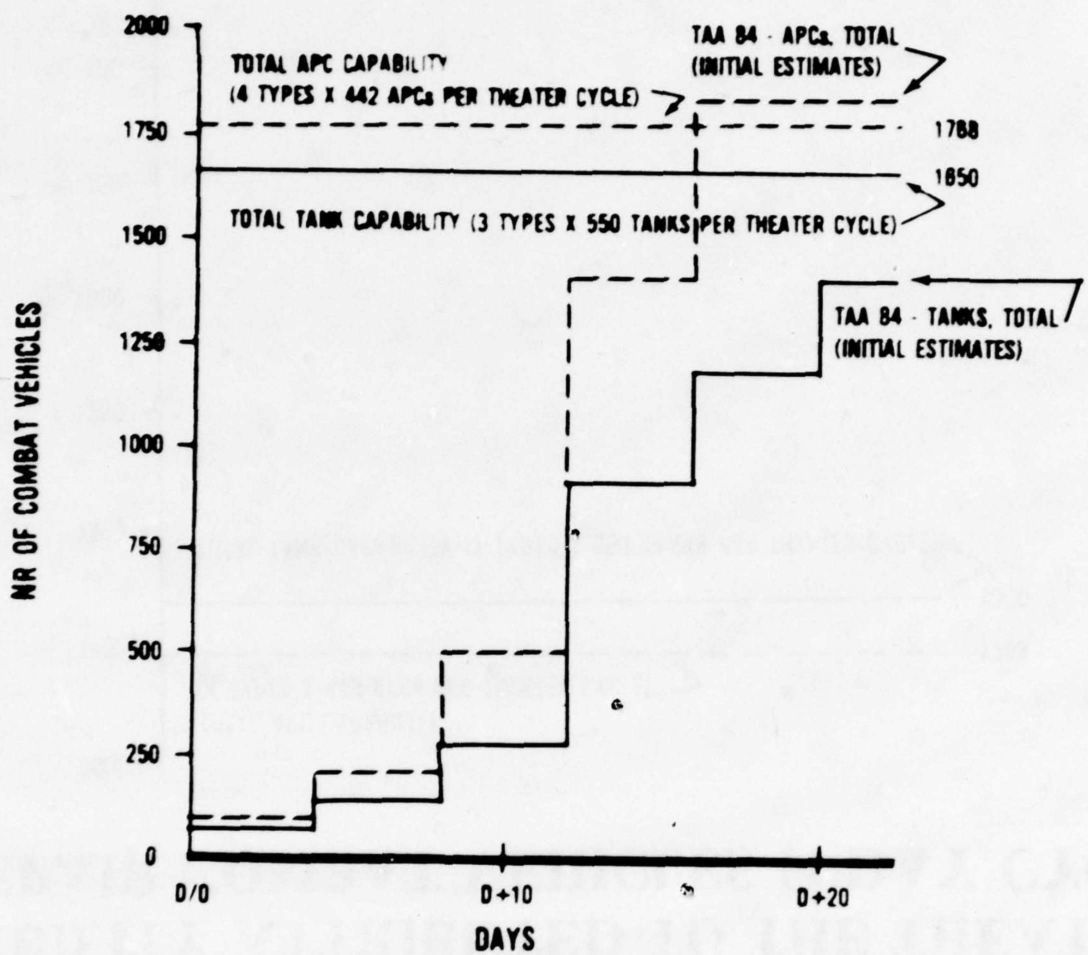
TANK LOSS EXPERIENCE (TOTAL)



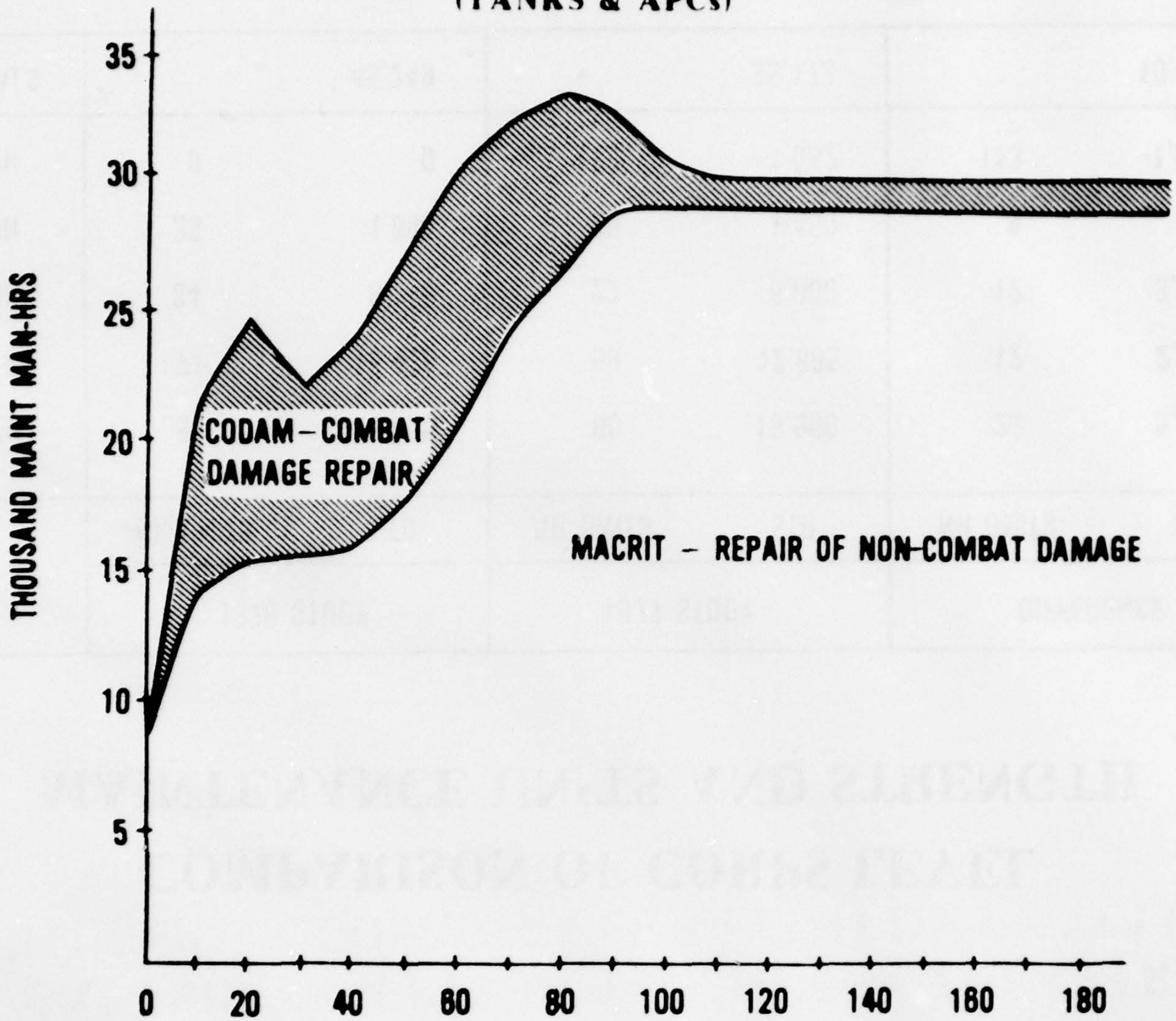
CAPABILITY ATTRIBUTED TO THE THEATER TO REPAIR COMBAT VEHICLES (4 DAY CYCLE)



CAPABILITY ATTRIBUTED TO THE THEATER TO REPAIR COMBAT VEHICLES (4 DAY CYCLE)



DAILY MAN HOURS OF MAINTENANCE REQUIRED TO REPAIR COMBAT VEHICLES
(TANKS & APCs)



COMPARISON OF CORPS LEVEL MAINTENANCE UNITS AND STRENGTH

SRC	1976 STUDY		1977 STUDY		DIFFERENCE	
	NR UNITS	STR	NR UNITS	STR	NR UNITS	STR
29-137H	83	18,675	60	13,500	23	5,175
29-207H	71	15,478	59	12,685	12	2,793
29-208H	34	9,248	22	6,006	12	3,242
29-136H	33	1,848	25	1,400	8	448
29-610H	0	0	113	1,582	113	-1,582
TOTALS		45,249		35,173		10,076

SHORTCOMINGS

- CAPABILITY OF THEATER TO REPAIR NOT BELIEVEABLE
- NORS DATA SUBJECTIVE/OPTIMISTIC
- RECOVERY TIMES OPTIMISTIC
- RESULT: CAPABILITY REDUCED (JUDGMENT CALL)
- APC DATA WEAK
- "A TANK IS A TANK. . . "
- CEM/FASTALS LINK IS MANUAL

VALUE

- SYSTEM NOW OPERATIONAL (TAA-84 AND OMNIBUS 78)
- PROMPTED CONSIDERATION OF SUPPORT FORWARD CONCEPT
  - CANNIBALIZATION
  - TRIAGE
  - COMBAT DAMAGE ASSESSMENT TEAMS
- GENERATED INTEREST (CODAM, SPARC, MASC)
- ILLUMINATED LOGISTICS FACTOR IN EQUATION OF FIREPOWER

ABSTRACT

<u>TITLE</u>: Computer Aided Battlefield Operations Management System (CABOMS)

AUTHOR: Mr. Valentin C. Berger
US Army Troop Support and Aviation Materiel Readiness Command

<u>ABSTRACT</u>: The purpose of this paper is to outline concepts for a computer-aided battlefield deployment and logistics support system. CABOMS is presented as a composite of automated and semi-automated capabilities supplied to field commanders in order to increase their perception and mastery of combat operations. The system is intended to supplement, rather than to replace, current combat operations management techniques. The paper stresses the automated reportage of weapon systems fuel and ammunition residuals as a means for increasing the effectiveness of logistics supply support activities.

SUBJECT: Computer Aided Battlefield Operations Management System (CABOMS)

AUTHOR: Mr. Valentin C. Berger

AGENCY: US Army Troop Support and Aviation Materiel Readiness Command (USATSARCOM)

1.0 PURPOSE

The purpose of this paper is to outline concepts for a computer-aided battlefield deployment and logistics supply support system. CABOMS is intended to provide realtime command, communications, and control for joint-service combat operations via fully automated and semi-automated data processing. Some elements of the proposed system are currently in existence, other elements are in process of development, and still others require definition, research, and experimentation. The CABOMS is intended to facilitate the implementation of US Army doctrine as set forth in FM 100-5.

2.0 ASSUMPTIONS

The presentations in this paper are based upon the following premises:

2.1 Military objectives can be defined quantitatively in terms of penetration distances and of other significant parameters, such as equipment and personnel losses and the interdiction of supply flows within the area of the battlefield;

2.2 Individual weapon systems (air and surface) can be defined quantitatively in terms of their physical characteristics and of their reaction and performance capabilities;

2.3 In tactical battlefield situations the achievement of military objectives depends upon the sustained concentration of firepower upon hostile targets in a situation where air and surface vehicles are in movement relative to each other. It follows that military advantage accrues to that force which achieves the larger degree of survivability and of effective logistic supply support while maintaining freedom of movement over extended periods of time;

2.4 Terrain topography in extensive areas of the world have been converted to a digitized format suitable for use in data processing machines;

2.5 A comparable digitized mapping effort is feasible for soil characteristics of potential battlefields;

2.6 A relatively fine-grid digitized representation of weather parameter dynamics is feasible in realtime over wide areas;

2.7 A number of models have been written and exercised that are capable of simulating engagements between friendly and hostile weapon systems. These programs may be used to determine kill probabilities resulting from simulated engagements, and to seek the minimization of friendly losses. Specifically, the models test various vehicle approach "tracks" for their vulnerability to hostile weapons' fire and determine the coordinates of the least vulnerable paths to their objectives.

2.8 Draft specifications have been prepared for a Joint Tactical Information Distribution System (JTIDS) (U). The JTIDS, as described in DCB Exhibit 7600, employs cryptographic encoding technology to construct a secure communications grid capable of distributing information on the exact location, identity, status, and intent of friendly and hostile air and surface force elements. It is presumed that the location, identity, and status of hostile weapon systems are obtained via active and passive intelligence - gathering means deployed in the FEBA and beyond it. The purpose of the JTIDS is, therefore, to provide in realtime an accurate and unambiguous representation of the tactical air and surface situation in the combat theater.

2.9 The judgment of executive military personnel is essential to the overall conduct of combat operations. Any automated deployment and support system is required to feature "man-in-the-loop" control for the performance of critical decisional functions.

3.0 CABOMS CONCEPTS

3.1 The key concept of the CABOMS is the integration into a realtime command, communications, and control system of the following elements:

a. The JTIDS, for the purpose of establishing a navigation, location, and communications grid projected over the battlefield;

b. A digitized topographical terrain representation of the battlefield;

c. A digitized representation of battlefield terrain soil characteristics relevant to the operation of wheeled and tracked vehicles, and of infantry personnel;

d. A digitized, continuously updated, representation of weather conditions over the battlefield, e.g. visibility, precipitation, wind parameters, temperature gradients, etc.;

e. The weapon system survivability assessment capabilities of EVADE-type computer models;

f. Models designed to compute, summarize, and display tactical situations for the benefit of military personnel;

g. Interactive Light Pen/CRT/Computer system, and communications equipment providing field commanders with access to computer facilities and to individual weapon systems for the purpose of guiding their movements;

h. Intelligence - gathering systems interfacing with the JTIDS; and

i. Computerized intelligence templating techniques.

3.2 Another key concept of the CABOMS is that each weapon system may be characterized by a Figure of Merit (FOM). As understood in the context of this paper, the FOM is a quantitative representation of the weapon system's capability to execute its design mission. It follows that:

a. The FOM is a function of the weapon system's potential target array. It is evident that the FOM of a gunship helicopter armed for anti-armor combat is at an absolute maximum when engaging tanks, personnel carriers, or truck convoys.

b. The FOM is a function of the weapon system's operating time since refueled and/or rearmed. The FOM of the helicopter above is near zero under either conditions of low fuel reserves or of ordnance exhaustion;

The FOM of each combat vehicle is, therefore, subject to variable-rate degradation proceeding from the utilization of on-board fuel, and to "stepped" degradation due to the expenditure of ammunition rounds (shells, rockets, bullets, etc). It is evident, then, that the FOM of each weapon system must be continuously updated via the JTIDS in order to construct in realtime a reliable picture of adversary tactical capabilities deployed on a battlefield. It is also evident that the quantification and aggregation of FOM's (at full design capabilities) must be based upon the "pairing" of each weapon system with each battlefield target within its design array. Resulting FOM values must then be stored in (computer memory) core where they may be accessed for the purpose of simulating the dynamics of tactical engagements.

3.3 A subsidiary concept of the CABOMS is the construction of Tactical Situation Ratios (TSR's) for use in the models of 3.1.d. It is presumed that the movement of air and surface weapon systems in any segment of a FEBA is composed of displacements normal to the "edge line" and of displacements parallel to that line. These displacements may be combined into "absolute" displacements. Further, weapon system movements are characterized by component and absolute velocities, and the weapon system itself is characterized by its Figure of Merit (FOM). The combination of directional displacement, absolute velocity, and FOM, may be used to model each weapon system in a tactical engagement as a vector relative to the JTIDS grid. The engagement can, therefore, be simulated for the benefit of the friendly commander via an optimization program. Specifically, the commander will be provided with the combination of weapon systems most likely to kill each hostile target with minimum losses, together with their requisite approach courses and velocities. The ratio of FOM's immediately prior to the engagement constitutes the projected TSR and is a basis for decision to proceed or not to proceed, and the post-engagement FOM ratio is the final TSR. It is evident that the projected TSR's over any significant length of the FEBA may be used to measure potential hostile breakthroughs, or, conversely, opportunities for the exploitation of friendly force advantages. Final TSR's may be used to trigger logistic support and to guide offensive or defensive redeployments of friendly resources. The TSR concept therefore provides an automated technique for:

a. Selecting friendly weapon systems combinations most likely to kill the hostile target;

b. Vectoring the weapon systems selected toward hostile targets;

c. Providing paths of minimized vulnerability for controlled weapon systems approaching their targets;

d. Measuring the projected and the final TSR ratios for discrete engagements and for the sum of engagements along extended FEBA segments;

e. Anticipating in quantitative terms the tactical weaknesses and opportunities present at any given time and in any given sector of the battlefield; and

f. Reacting appropriately to the anticipated situations.

3.4 A second subsidiary CABOMS concept relates to the variable FOM of weapon systems. The FOM is capable of degradation (from the offensive point of view) as the weapon system consumes its fuel and ammunition reserves. The FOM is therefore sensitive to the utilization rate and utilization time of each weapon system, and must be recomputed continuously or at discrete time intervals. It is evident also that the functioning of the logistic support system must be guided to maintain the FOM of individual weapon systems as close to their design values as possible. Under the dynamic conditions of the battlefield, this "optimization" process must be exercised continuously, leading to the concept of computer-aided supply support of friendly forces. Specifically, the iterative display of FOM status for all friendly weapon systems will be used by field commanders to vector required supplies to the appropriate FARRP's and/or to individual systems via the least vulnerable tracks. Simultaneously, commanders can direct degraded weapon systems to the FARRP's that are being resupplied, and vector undegraded systems to sectors where tactical engagements are imminent or are in progress. Computer-aided battlefield management is thus geared to shift the flow of materiel and supplies rapidly towards points of consumption, to project shortages in time and space before they occur, and to match tactical engagements to supply support capabilities.

3.5 The preceding discussions have indicated that the JTIDS locates hostile target/weapon systems within the friendly navcom grid. This capability of the JTIDS may be coupled with digitized terrain and weather information and with EVADE-type techniques to determine the least vulnerable approach tracks for enemy weapon systems. The same capability may be used to estimate the FOM of hostile systems as a function of their known performance characteristics and their displacement parameters (running time, velocity, etc). The friendly commander can, in effect, play his opponent's game and proceed to spoil it. Specifically, he can attempt to stretch or to block "safe" tracks, he can anticipate enemy resupply needs and interdict their fulfillment, and he can direct maximum-FOM friendly systems to engage degraded-FOM targets. It is anticipated that these activities will be carried out in realtime and will be integrated with the management of friendly forces and supply support.

3.6 Weather and terrain intelligence briefly described in 2.4, 2.5, and 2.6 is essential to the effective implementation of command,control, and tactical war-gaming per 3.3 above. The topography of the battlefield and the physical dimensions of the ground cover determine the amount and location of masking available to surface vehicles and to helicopters flying NOE. To a lesser extent the same features can mask the flight of (ground-support) tactical aircraft. Soil-type intelligence combined with precipitation and moisture data is of use in plotting navigable tracks for wheeled and tracked vehicles traveling off-road. Visibility and other weather parameters are critical to joint air-surface operations, as well as to the selection and use of equipment designed to overcome certain types of environmental constraints, e.g. darkness.

It is evident, then, that both the static and the dynamic elements of the battlefield environment interact with the weapon systems themselves in an extremely complex manner. The utilization of computer data processing is the logical approach to dealing with the perceived complexities.

3.7 The various concepts presented heretofore require a vizualization of the forward battlefield commander's post, and of some of the hardware and software needed to make the CABOMS work. The Colonel-level commander is seen facing three display CRT screens:

3.7.1 The General Tactical Deployment Display (GTDD) screen showing weapon systems symbols superposed on a grid map of the command's segment of the battlefield. The GTDD is updated automatically at rates appropriate to the ground speed of various types of vehicles. Each weapon system symbol represents a maneuver grouping of actual vehicles and appears at the instantaneous "center of gravity" of the grouping. Distinctive coding differentiates friendly from hostile groupings, and identifies the type and number of weapon systems in each grouping.

An alternate GTDD presentation is available on this screen via manual command. This display converts each maneuver grouping symbol into its aggregated FOM, identifying friend and foe.

The GTDD system is provided with a display recall capability, also via manual control. The Console operator selects a retrograde number of updates, and the screen displays the trace of the weapon systems groupings, ending with their most recent position relative to the JTIDS grid. Individual past displays may also be recalled for reference.

A parallel capability is provided for the FOM display, for the recall of any selected past set of numbers, or of the presentation of a sequenced set of data. Increase/decrease trends for individual vehicle groupings are flagged distinctively. Friendly/hostile force imbalances are also flagged for the entire command's segment of the battlefield.

The GTDD additionally displays the position of FARRP's and their status in coded form, as well as the location and status of rear echelon logistic facilities and supply concentration points.

3.7.2 The Selected Tactical Deployment Display (STDD) screen designed as a subsidiary of the GTDD. All of the functions of the GTDD are made available in the STDD, except that a manually selected section of the JTIDS net is "blown-up" on the STDD screen. The purpose of this display is to provide a fine-grained view of individual weapon systems, of their positional and FOM status, and of their recent "histories".

The commander is seen using the STDD for "management-by-exception" when specific weapons groupings are flagged for attention on the GTDD screen.

3.7.3 The third screen is the Tactical Projection Display (TPD) which permits the forward commander to "war game" off-line selected engagements within his area. The TPD can be slaved to either the GTDD or to the STDD consoles via manual control. Using a Light Pen, the commander "shifts" either

maneuver groupings or individual weapon systems toward their objectives, taking into account their prior trace displays on the GTDD or the STDD screens. On manual command, the TPD accesses the computer facility, and following the requisite processing delay, the CRT displays minimum vulnerability tracks, the minimum and maximum track travel times, and the projected TSR's assuming all weapons, friendly and hostile, are used optimally, and all vehicles follow the least vulnerable tracks closely en route to their engagement points.

If the projected TSR's are favorable to the commander's forces, he switches the "war plan" to an active mode, and appropriate directional information is communicated automatically to each friendly weapon system grouping or vehicle. If the projected TSR's are unfavorable, the commander can replay the input traces off-line with systematically stepped speed changes, can change all or some of the traces, or can improve the projected FOM balance via support vectored to specific grid coordinates.

Following the decision to activate a particular "war plan", the GTDD (or STDD) updates are automatically transferred to the TPD screen in the form of traces. The commander can thus observe the movement and status of friendly and hostile forces in realtime, with display updates of FOM's and of projected TSR's. As hostile forces react to his approach, the commander can take the TPD off-line and, using the Light Pen, can refine and adjust his closing deployments and forward supply support, project new TSR's and "activate" the changes by returning on-line.

It is noted that the three CRT displays mentioned above can be integrated into a multi-function device capable of being switched from mode to mode as needed. It is further noted that command posts as described here can be linked electronically to achieve handoff capability in the event that a post malfunctions or is destroyed. Handoff would be accomplished through grid compression, and could also be used by commanders along the FEBA to monitor adjacent sectors of the battlefield.

3.8 The command posts of 3.7 constitute the "front line" of the CABOMS, and their coverage of combat activities corresponds to the Colonel's Area (0 - 50 kms depth) at the GTDD level and to the Captain's Area (0 - 5 kms depth) at the STDD level. The TPD system is therefore, intended to enable the management of zones of direct fire as well as of zones of indirect fire, counterfire, and tactical maneuver. With reference to the US Army's Operations FM 100-5, a real-echelon command post is envisioned for the purpose of implementing the functions of the CABOMS in the General's Area (0 - 150 kms depth) of the battlefield. Given the General's assigned overview of support and of tactical reinforcement, the following CRT displays and functional resources are envisioned for his command post:

3.8.1 An integrating GTDD/TPD system capable of interfacing with a large number of forward GTDD/TPD systems strung out along the FEBA. The interfacing function will be controlled via grid compression/expansion techniques to display variable-length segments of the FEBA. This system will access and display GTDD or TPD information appearing on-line or off-line on forward CRT's. It is noted that this capability provides double redundancy for the forward echelon command post, since they are also capable of handing-off their functions/displays to adjacent posts per 3.7.3.

3.8.2 A software system capable of processing intelligence data within the command area, and displaying on the post's GTDD/TPD screen (s) the disposition of all major force elements deployed on the battlefield. The technique required for execution of this function is an elaboration of intelligence templating wherein the presence of specific hostile weapon systems within a particular portion of the JTIDS grid is related to the terrain and to the enemy's known doctrinal deployment concepts. Computerized templating is envisioned as a dynamic process proceeding over a period of time, i.e. as a combined disposition and event templating process. The symbolic representations of force elements on the GTDD/TPD screen (s) will be "animated" so as to display their directional movement across the battlefield along with subsidiary time and velocity information. A companion animated display of the General's allotted force elements will be provided on the GTDD/TPD screen (s), permitting the use of the Light Pen to "war game" a limited number of large-scale tactical moves and engagements designed to deal with the perceived threat. Upon selection of deployments with favorable projected TSR's, the off-line TPD is placed on-line and is broken out to the forward echelon TPD's where the Colonels proceed to refine (per 3.7.3) sectional deployments and transmit them to maneuver groupings of joint combat arms within their jurisdiction.

3.8.3 A software/hardware system capable of "war gaming" off-line the integrated, time-phased, support of tactical combat operations within the General's Area of the battlefield. This function is "slaved" to the management of joint combat arms force elements described in 3.8.2 above. Specifically, the supply support requirements of each battlefield segment are identified and updated continuously on the display screen. The General Officer, or his proxies, use the Light Pen and a keyboard to integrate the total demand for ammunition, POL, maintenance items, and personnel, and to direct available resources towards the demand points. Diagnostic displays of deficiencies, time delays, and shortages are displayed for analysis until the commander accepts a particular CRT display of logistic support distribution in space and time. At that point, the rear-echelon post commander "activates" the support scheme by going on-line, and the forward commanders' GTDD and TPD systems are made to reflect the progress of support activities in their respective battlefield segments.

3.8.4 A system for representing on the General's GTDD/TPD screen (s) in symbolic form the deployment of EW systems across the battlefield. The system will display and identify ESM, ECM, and ECCM activities, friend and foe, and use automated intelligence templating techniques in support of the commander's tactical "war gaming" for the deployment and support of joint force elements. Animated displays of EW operations provide a spacial and chronological imaging of tactical deployments that may be used to confirm the validity of animated force elements templating executed per 3.8.2.

3.8.5 A system capable of abstracting in GTDD and TPD presentations the symbols corresponding to specific friendly and hostile combat arms systems, maneuver groupings, and force elements, along with FOM, TSR, and other parameters relevant to them. This software/hardware system is intended to enable "specialists" to manage their systems separately during selected engagement sequences, to troubleshoot, and to "war game" the timing and support of integrated tactical operations. These functions are particularly relevant to

the management of close air support of nuclear tactical weapon systems, of POL and ammunitions supply support, and of EW operations. During critical phases of tactical engagementss a multiple CRT array could serve to provide each specialist with his GTDD/TPD screen and Light Pen, leading to the concept of the Command Post Van (CPV).

3.9 The Command Post Van is envisioned as an air-transportable off-the-road "vehicle". The CPV is designed to accomodate an encoding/decoding/communications center, a power supply system (generator set), and a center for the operation of a command GTDD/TPD CRT console flanked by subsidiary CRT consoles for specialized combat arms operations per 3.8.5 above. Command communications will be implemented in encrypted format via secure lines to outlying amplifier-antenna stations located at some distance from the CPV. The CPV is not envisioned as containing a data processing facility. Such an installation would be located at a considerable distance from the battlefield, and would accomodate on a time-sharing basis the computational requirements of an array of command posts covering an entire combat theater.

3.10 Looking towards the individual weapon systems engaged in coordinated tactical operations, the CABOMS requires that they be capable of interfacing with its various elements of command and control. Specifically, individual weapon systems must be capable of:

a. Communicating (via the JTIDS network) their position relative to targets;

b. Reporting their POL and ammunition reserves status;

c. Reporting their altitude, directional, and velocity parameters; and

d. Receiving timing, altitude, directional, and velocity parameter instructions from command posts.

It is assumed that in addition to these capabilities, weapon systems such as helicopters, armored vehicles, and artillery vehicles are provided with self contained navaids and fire control systems. It is therefore presumed that CABOMS - related displays of track and timing guidance information will be used in conjunction with on-board systems to enhance the survivability and combat effectiveness of each weapon system as it engages maneuvering targets. The CABOMS functioning in, say, a tank, is envisioned as operating via two side-by-side CRT's. The first of these would display an array of potential targets, and the tank itself, on a JTIDS - generated grid and in the form of animated traces generated by successive positional updates. The second CRT would display (on manual command) the bearing, velocity, and altitude of any selected target within the array, and the course and running parameters needed for the tank to close with target within optimum range of the tank's weapon. Both of these sets of information are updated at discrete intervals, in response to tracking of the target on the one hand, and to the iterated computation of the least vulnerable approach track for the tank on the other. As the engagement point is neared, the tank commander activates his fire-control system and attacks the target. In the event of success, he selects another target assigned via the first CABOMS CRT, and is guided to engage it along a path of reduced vulnerability The process is repeated until the entire target array, or the tank itself, is killed.

In a defensive mode of operation, the tank commander can request a reduced vulnerability track away from an oncoming hostile weapon system. In the event that the closing rate is not excessive, the CABOMS provides requisite velocities, timing, and heading changes. In the event that the enemy is too close or too fast, the CABOMS provides a visual indication of incompetence, and the commander deals with the situation via on-board systems only.

An alternative to the installation of CABOMS - related CRT's in each and every weapon system (tank, helicopter, etc.) is the provision of that equipment in selected vehicles assigned to operate in conjunction with maneuver and/or force elements. Vehicles equipped in this manner may then be deployed across the battlefield when and where needed. It is envisioned that these mobile command posts would relay command guidance and control information to fielded weapon systems, and report status and deployment dynamics data to the forward command posts of 3.7 and 3.8.

3.11 It is emphasized that the CABOMS is not intended to replace human judgment in either command posts or in the cockpits of individual weapon systems. The system deliberately "mimics" the interactive dynamics of command, control, and communications as they exist today. At the same time, the system strives to expand the data base for human decision-making and to augment the speed with which complex data is reduced to a comprehensible format. Finally, the CABOMS is intended to provide guidance and assistance, rather than orders to the crews of fielded weapon. It is expected that crews engaged in combat will use their full repertoire of on-board equipment and training resources, and that they will use the CABOMS displays and terminals to good effect.

4.0 THREATS TO THE CABOMS

4.1 The enemy threat to an operational CABOMS deployment is expected to include physical damage to CPV's, electronic countermeasures to JTIDS transmissions, eavesdropping, signal intercept activities (spoofing, etc.), and strategic attack against computer facilities and/or relay satellites. It is expected that CPV's will be actively defended by airmobile elements and by AA weapons, and that the full spectrum of ECCM techniques will be used to protect the distribution of data within the battlefield.

4.2 An important friendly threat to an operational CABOMS deployment is a console operator's error in assigning information and/or commands to the computer, initiating thereby a garbage-in/garbage-out sequence of management data. This threat may be reduced by means of programmed diagnostic check loops designed to test the validity of input commands and data. Improper commands and/or inconsistencies can be identified on CRT's for attention and correction.

Another means for reducing the above threat is to automate as much of the status and position reportage as possible. For example, the tank of 3.10 can be equipped with electromechanical means for transmitting its grid position, fuel status, velocity, and weapons utilization data without requiring the attention of its crew. It is evident that full automation of repetitive or continuous tasks of this type decreases the workload of combat personnel and

contributes to the overall effectiveness of the CABOMS.

4.3 Probably the most important threat ot the effective operation of the CABOMS is the technical feasibility of realtime computer/weapon systems interfacing. It is recognized that the computational speed and capacity of existing non-experimental computers falls short of the needs of a genuine realtime CABOMS. It is therefore necessary to rely on intermittent guidance interfacing between tactical force elements in rapid movement and computer facilities accessed via command posts as described in this paper. Development of an effective CABOMS must target this problem and resolve it through the use of elegant software, as well as via the development of reliable computer systems capable of extremely fast operation with immense sets of data bits.

4.4 In conclusion, it is highly probable that there exist no alternative to the development of a CABOMS-type of battlefield command and control system for the purpose of winning the "first battle" and the battles following, if any.

LIST OF ACRONYMS

CABOMS	Computer Aided Battlefield Operations Management System
CPV	Command Post Van
CRT	Cathode Ray Tube
ECM	Electronic Countermeasures
ECCM	Electronic Counter-Countermeasures
ESM	Electronic (Warfare) Support Measures
EW	Electronic Warfare
FARRP	Forward Area Rearming and Refueling Point
FEBA	Forward Edge of Battle Area
FOM	Figure of Merit
GTDD	General Tactical Deployment Display
JTIDS	Joint Tactical Information Distribution System
NOE	Nap-of-the-Earth
STDD	Selected Tactical Deployment Display
TSR	Tactical Situation Ratio
TPD	Tactical Projection Display

TITLE: Economic Analysis of Reliability Improvement Warranties for Army Aviation Systems

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ABSTRACT: Within the Army Aviation Research and Development Command (AVRADCOM) much attention is being focused on the use of the reliability improvement warranty (RIW) as a means of improving field reliability. Many items of Army aviation equipment, including the T-700 engine, scheduled for procurement are being considered as candidates for a RIW. In order to determine the effectiveness of a RIW for a given procurement it is necessary to conduct an economic analysis of the proposed RIW. This office has developed a computer model specifically to conduct the required economic analysis. In its present form the model was specifically designed to analyze the proposed T-700 warranty and is presently only being exercised in this context. However, it is easily adaptable to a more general class of problems and its capabilities will increase as futher warranties are analyzed.

ECONOMIC ANALYSIS OF RELIABILITY IMPROVEMENT
WARRANTIES FOR ARMY AVIATION SYSTEMS

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1. INTRODUCTION

In recent years the Army has placed increasing emphasis on the use of the reliability improvement warranty (RIW) to improve the reliability of fielded equipment. In spite of this emphasis, the RIW is a recent development in Army procurement and there is still only a limited amount of experience in its application. Most of this experience is in the procurement of electronic equipment and only recently has it been considered for application to nonelectronic equipment. An example of such an application is the proposed new equipment limited warranty for the T-700 engine, the powerplant for the UH-60A Blackhawk.

The key to the successful application of an RIW is to negotiate a proper warranty price. There are lower and upper bounds within which the warranty price must lie if it is to accomplish its purpose. It should not be so low as to put the contractor in serious threat of bankruptcy but, on the other hand, an excessively large price will negate any benefits to the Army.

The methodology and computer model discussed here were specifically designed as a tool to determine the worth of the proposed T-700 engine warranty to the Army. The computer model was specifically designed around the T-700 warranty and, at present, is only being exercised in that context. However, it is easily adaptable to a more general class of problems, which would include other components than engines, and its capabilities will increase as additional warranties are analyzed.

2. WARRANTY ECONOMIC ANALYSIS LOGIC

During the first three years of T-700 engine deliveries the engine will be supported by the contractor. The contractor will essentially perform the functions of a depot while an Army depot capability is being developed. During this three-year contractor support period the field reliability of the engine will be covered by a new equipment limited warranty. Under the provisions of this warranty the contractor is responsible for all failures caused by defects in material and workmanship provided that such failures occur within the three year support period or within 500 hours of running, whichever comes first. The contractor will absorb all or part of the costs of correcting all failures during the warranty period. The percentage of repair costs borne by the contractor is determined by the formula shown in Figure 1.

The price of the warranty will be negotiated as a separate line item in the contract. To obtain his estimate of the warranty price, the contractor will estimate the reliability that can be expected from the engine over the warranty period and, from this, determine the expected number of failures. The contractor will then determine the cost of repairing the forecast number of failures plus a percentage added as a risk buffer against possible errors in his forecasting. The amount of his bid will be determined primarily by his estimate of the reliability of the engine over the warranty period and the amount of risk buffer he adds.

At first glance it would appear that the Army has nothing to gain with such a warranty as it is still paying, albeit indirectly, for the failures. This is not the entire story, however, as a properly applied warranty can bring substantial savings in operating costs to the Army. Since the contractor's profits are directly related to the items reliability in service use, he has a strong incentive to introduce reliability improvements in an expeditious manner. These improvements will be introduced as engineering change proposals installed at no cost to the Army. These reliability improvements in the early part of the equipment's life cycle should maximize the rate and amount of reliability growth. Improved reliability results in savings in operating cost. If the savings in operating cost due to the improved reliability are greater than the cost of the warranty, then the warranty has accomplished its purpose.

In order to get the maximum benefits from a warranty the Army must insure that the contractor does not charge an excessive price for it. An excessively large warranty fee will reduce the contractor's motivation to improve reliability because he will be less susceptible to the consequences of poor reliability. In addition, if the warranty cost is excessive enough, the warranty will not have economic benefit over the engine's life cycle even though substantial improvements in reliability were obtained during the warranty period.

The situation is represented graphically in Figure 2. The curve $A_0B_1C_0$ represents the cumulative cost of the no warranty alternative plotted against time. This alternative is the management decision not to buy a warranty during the contractor support period. For simplicity it is drawn as a straight line. The curve $A_1B_1C_1$ represents a baseline warranty alternative. The distance A_1-A_0 represents the cost of the warranty. The cumulative costs of the warranty alternative at first increase at approximately the same rate as the no warranty alternative. However, due to reliability improvements incorporated by the contractor, the slope of this curve decreases until the end of the warranty period is reached. B_1 is the "breakeven point." This is where the cumulative costs of both alternatives are equal. At this point the savings due to the reduced operating costs of the warranty alternative have paid back the cost of the warranty. The savings over the life cycle due to the warranty is represented by the distance $C_0 - C_1$.

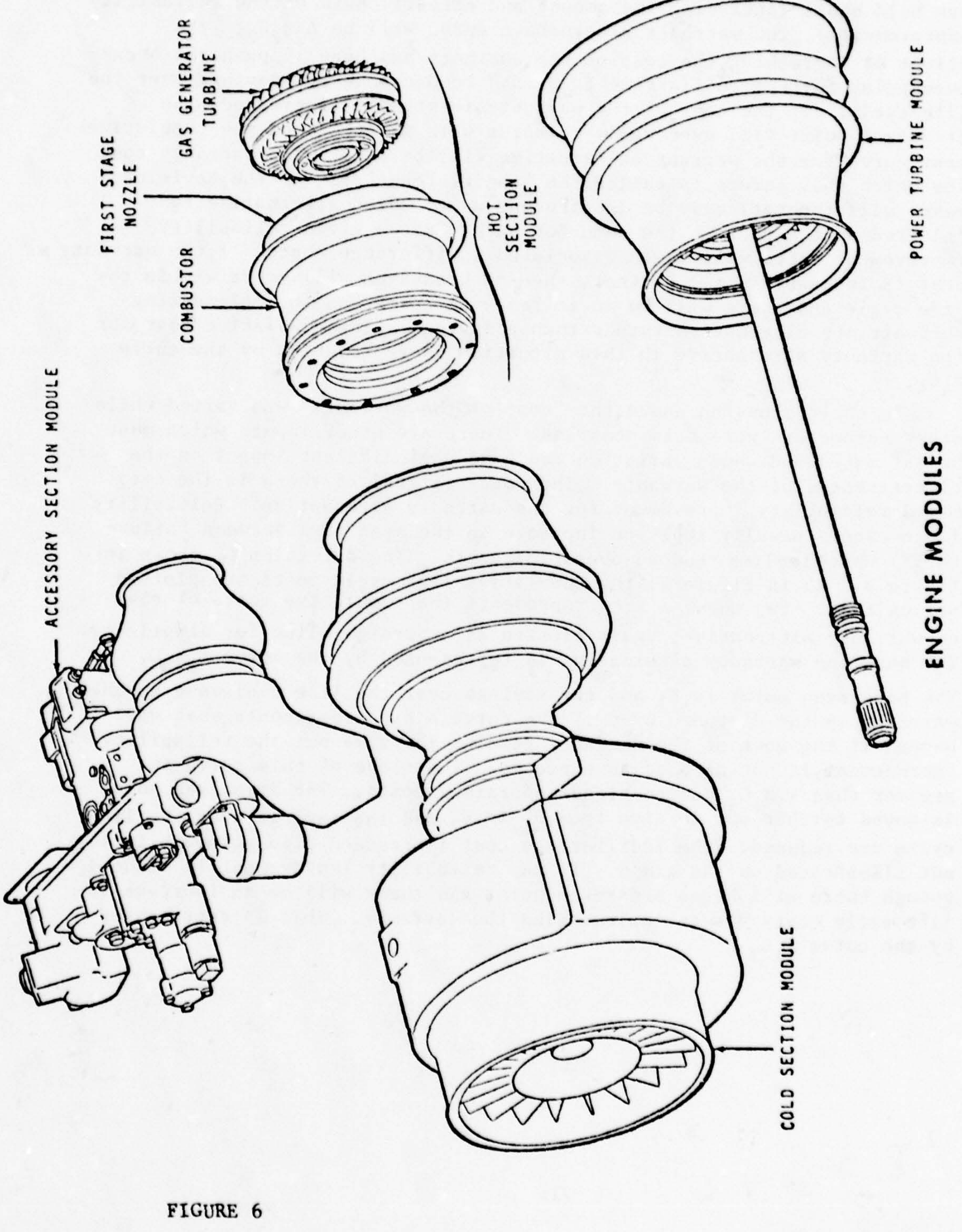
ACCESSORY SECTION MODULE
COMBUSTOR
FIRST STAGE NOZZLE
GAS GENERATOR TURBINE
HOT SECTION MODULE
POWER TURBINE MODULE
COLD SECTION MODULE
ENGINE MODULES

FIGURE 6

If the cost of the warranty is increased while all other factors are held equal (including the amount and effectiveness of the reliability improvements), the warranty alternative curve will be $A_2B_2C_2$. The effect of increasing the cost of the warranty has been to push the breakeven point further out in time to B_2 and to decrease the savings over the life cycle. If the cost of the warranty is steadily increased, the breakeven point will eventually coincide with point C_o and the cumulative cost curve for the warranty alternative will be A_3C_o. The warranty cost for which this occurs is called the "indifference cost". The decision maker will theoretically be indifferent as to which alternative is selected as the cost is the same for both. For a given reliability improvement there will be an associated indifference cost. If the warranty's cost is increased still further, then no breakeven will occur within the life cycle and there will be an increase in costs due to implementing the warranty alternative rather than a savings. The cumulative cost for the warranty alternative in this situation is represented by the curve A_4C_4.

In the discussion above the "cost of the warranty" was varied while other parameters were held constant. There are other inputs which must be estimated and whose variation can have a significant impact on the effectiveness of the warranty. The most critical of these is the estimated reliability improvement for the warranty alternative. Reliability improvements usually imply an increase in the mean time between failure (MTBF) which implies reduced operating costs. The situation is shown in Figure 3. As in Figure 2, the cumulative life cycle costs are plotted versus time. The curve $A_oB_1C_o$ represents the cumulative costs of the no warranty alternative, again plotted as a straight line for simplicity. The baseline warranty alternative is represented by the curve $A_1B_1C_1$. The breakeven point is B_1 and the savings over the life cycle due to the warranty is the distance C_o-C_1. The curve $A_1B_2C_2$ represents what will happen if the cost of the warranty remains the same but the reliability improvement is not as good as expected. The slope of this curve is greater than $A_1B_1C_1$ due to higher operating costs. The breakeven point is moved further out in time from B_1 to B_2 and the savings over the life cycle are reduced. The indifference cost is reduced also although it is not illustrated on the graph. If the reliability improvement is reduced enough there will be no breakeven point and there will be an increase in life cycle costs due to implementing the warranty. This is represented by the curve A_1C_3.

3. DESCRIPTION OF COMPUTER MODEL

3.1 OVERVIEW

The computer model is based on the logic described above. For a given forecast reliability improvement the model will determine three measures of effectiveness. These are the savings in life cycle costs, the time of breakeven for a baseline warranty cost and the indifference cost.

The model is deterministic and handles the important operational parameters and costs as monthly time series. The life cycle costs are determined on a monthly basis and accumulated as the program progresses from the first to the last month of the warranty's economic life. The model logic is outlined in Figure 4.

The program first reads the input data and then initializes for the monthly time series computations. The computations labeled "monthly analysis" are then performed for each month of the warranties economic life. Within the monthly analysis cycle the costs for the current month for both the no warranty and warranty alternatives are determined and added to their respective total life cycle costs. The difference between the total no warranty and warranty alternative life cycle costs are then determined. This difference is the quantity of interest and not the absolute value of either alternative's cumulative life cycle costs as determined by the model. Only those costs which are different between the two alternatives are determined by the model. At the end of the monthly analysis cycle the difference in life cycle costs is checked to see if the breakeven point has been reached. If so, the month in which it occurs is flagged. When the last month of the warranty's economic life has been analyzed, the indifference costs for various periods of time are determined. The indifference cost associated with a certain period of time is the maximum cost a warranty can have and still have a breakeven within that period of time. The period of time is measured from the beginning of the warranty period. The results of the analysis are then printed out. If sensitivity analysis is to be run on the engine's forecast reliability, new reliability data is read and the model is rerun. If not, or if the sensitivity analysis has been accomplished, the program terminates. Some of the more important operations indicated in Figure 4 are discussed in detail below.

3.2 REQUIRED INPUT DATA

The required input data is listed in Table 1. One of the important differences between the T-700 and previous Army aircraft engines is the modular construction of the T-700. The T-700 is shown in Figure 5 and its four modules are shown in Figure 6. These four modules will be managed separately, individual modules incurring damage and being repaired rather than entire engines. This modular construction requires that some inputs be duplicated for each module rather than inputed for the complete engine. These inputs are listed in Table 1.

TABLE 1
REQUIRED INPUT DATA

GENERAL INPUT DATA

Length of study period (years)

Aircraft fleet size at beginning of study period

Engine inventory size at beginning of study period

Annual discount rate

Field labor cost ($/manhour)

Engine operating hour factor

Number of engines per aircraft

Number of modules

Baseline warrantly cost

First month of contractor support period

Length of contractor support period

New production aircraft delivery schedule

New production engine delivery schedule

Flying hour program

Time phased R&D and investment costs unique to the no warranty alternative

Time phased R&D and investment costs unique to the warranty alternative

MODULE DATA

Round trip cost from AVIM to contractor repair facility

Round trip cost from AVIM to Army depot repair facility

Manhours to remove and reinstall

Cost to repair in contractor's facility

Cost to repair in Army depot facility

Time phased forecast MTBRDR for no warranty alternative

Time phased forecast MTBRDR for warranty alternative

The most critical of the listed inputs are the mean times between removal for depot repair (MTBRDR) for the no warranty and warranty alternatives. Differences in these two inputs determine the difference in reliability between the two alternatives which, in turn, is the major factor determining the difference in life cycle costs between the two alternatives. These inputs are estimated from a limited amount of data and are subject to uncertainty. The critical nature of these inputs and their imperfect estimation requires that they be subject to sensitivity analysis. To fill this need the model has a built in capability to conviently conduct such sensivity analysis.

3.3 MONTHLY ANALYSIS COMPUTATIONS

The monthly analysis computations for the warranty alternative are outlined below.

The discount rate is determined from the following equation.

$$DRM(M) = 1/(1+MDR)^{M}$$

where

DRM(M) = The discount rate for the current month M.

MDR = The simple monthly discount rate that is equivalent to the inputed simple annual rate.

MDR is determined from the following equation.

$$(1 + MDR)^{12} = 1 + ADR$$

where

ADR* = Simple annual discount rate.

The aircraft fleet size and engine inventory size for month M is determined from the following equations.

$$NAM(M) = NAM(M-1) + NPA(M)$$

$$NEM(M) = NEM(M-1) + NPE(M)$$

where

NAM(M) = Aircraft fleet size for month M.

NPA(M)* = New production aircraft delivered during month M.

NEM(M) = Engine inventory size for month M (Includes both installed engines and spares).

NPE(M)* = New production engines delivered during month M (Includes both installed engines and spares).

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* Indicates input data

The total fleet flying hours and total engine operating hours for month M are determined from the following equations.

$$FHM(M) = NAM(M) \times FHP(M)$$

$$OHM(M) = FHM(M) \times NIA \times OHF$$

where

FHM(M) = Total fleet flying hours for month M.

FHP(M)* = Scheduled flying hours per aircraft for month M.

OHM(M) = Total engine operating hours for month M.

NIA* = Number of engines per aicraft

OHF* = Engine operating hour factor. Used to account for engine test and ground running. (current value used is 1.3)

The composite failure rate and the module failure weights are determined from the following equations.

$$FR2(I,M) = 1/MTBR2(I,M);\ I=1,\ \ldots,\ NMOD$$

$$CFR2(M) = \sum_{I=1}^{NMOD} FR2(I,M)$$

$$WT2(I,M) = FR2(I,M)/CFR2(M);\ I = 1,\ \ldots,\ NMOD$$

where

FR2(I,M) = Failure rate (failures/operating hour) for module I during month M for warranty alternative.

MTBR2(I,M)* = Mean time between removal for depot repair for module I during month M for warranty alternative.

NMOD* = Number of modules

CFR2(M) = Composite failure rate for month M for warranty alternative.

WT2(I,M) = Module failure weight. Fraction of total engine removals due to failure of module I during month M for warranty alternative.

In all computations involving failure rates the assumption is made that during month M the MTBRDR of Module I is exponentially distributed with mean MTBR1(I,M) and MTBR2(I,M) for the no warranty and warranty alternatives respectively.

For modeling purposes five modules were defined for the T-700 engine. Four of these corresponded to the four modules into which the T-700 can be physically broken, the cold section, the accessory section, the hot section and power turbine. The MTBRDR inputed for these modules is that corresponding to failure modes unique to the individual modules. A fifth module was added to account for failure modes that affected the whole engine and which required a complete engine overhaul.

The number of failures during month M for the warranty alternative (NF2(M)) are determined by the following equation.

$$NF2(M) = CFR(M) \times OHM(M)$$

The cost of field (AVUM or AVIM) labor caused by failed engines is determined by the following equations.

$$WMRR2(M) = \sum_{I=1}^{NMOD} WT2(I,M) \times MRR(I)$$

$$CRR2(M) = NF2(M) \times FLR \times WMRR2(M) \times DRM(M)$$

where

WMRR2(M) = Average manhours at AVUM and AVIM level associated with a failed engine during month M for the warranty alternative.

MRR(I)* = AVUM and AVIM maintenance manhours associated with a failure of Module I.

CRR2(M) = Total field labor costs due to failed engines during month M for the warranty alternative.

FLR* = Field labor rate (Dollars/Manhour)

The shipment costs caused by engine failures are determined by the following equations.

$$WSC2(M) = \sum_{I=1}^{NMOD} WT2(I,M) \times SCC(I) \text{ if } M \leq LMSP$$

$$WSC2(M) = \sum_{I=1}^{NMOD} WT2(I,M) \times SCD(I) \text{ if } M > LMSP$$

$$CSRF2(M) = NF2(M) \times WSC2(M) \times DRM(M)$$

where

WSC2(M) = The average roundtrip shipment costs between AVIM and the repair facility associated with a single engine failure during month M for the warranty alternative.

SCC(I)* = The costs of roundtrip shipment between AVIM and the contractor's repair facility of one Module I.

SCD(I)* = The costs of roundtrip shipment between AVIM and the Army depot repair facility of one Module I.

LMSP* = The last month of the contractor support period.

CSRF2(M)= Total shipment costs during month M for Warranty alternative.

It is assumed that prior to and during the contractor support period all repairs will be done at the contractor's repair facility. After the end of the support period all repairs will be done by the Army depot facility.

The engine repair costs are determined by the following equations.

$$WCOH2(M) = \sum_{I=1}^{NMOD} WT2(I,M) \times COHC(I), \text{ if } M \leq LMSP$$

$$WCOH2(M) = \sum_{I=1}^{NMOD} WT2(I,M) \times COHD(I), \text{ if } M > LMSP$$

$$COH2(M) = NF2(M) \times WCOH2(M) \times GCFM(M) \times DRM(M)$$

where

WCOH2(M) = Average repair cost of a single failed engine during month M for the warranty alternative.

COHC(I)* = Average cost to repair one module I in the contractor repair facility.

COHD(I)* = Average cost to repair one module I in the Army depot repair facility.

COH2(M) = Total repair costs to the Army during month M for the warranty alternative.

GCFM(M) = Government Cost Fraction for month M.

The Government Cost Fraction is a factor used to account for the fact that the repair costs are prorated between the Government and the Contractor in the warranty alternative. Prior to and subsequent to the support period the government will pay all the cost of repairs so GCFM(M) = 1 during this period. The value of the Government Cost Fraction during the contractor support period can be less than one. The manner in which this quantity is computed will be discussed later.

After the above costs are computed the total warranty costs are updated as follows.

RDIC = IC2(M) x DRM(M)

WC = 0, if M $\neq$ IMSP

WC = BWCOST x DRM(M) if M = IMSP

TC2(M)= TC2(M-1) + CRR2(M) + CSRF2(M) + COH2(M) + RDIC + WC

where

TC2(M)= Total warranty alternative cost at end of month M.

IC2(M)*= Miscellaneous research and development and investment costs incurred during month M by the warranty alternative.

BWCOST*= Baseline warranty cost

IMSP* = Initial month of the support period.

The quantity IC2(M) and the corresponding quantity for the no warranty alternative, IC1(M), are used to account for various nonoperating cost differences between the no warranty and warranty alternatives. An example of such a difference would be the need for the Army to fund a reliability improvement program in the no warranty alternative. No such program is required for the warranty alternative. In addition all product improvement proposals (PIP) and engineering change proposals (ECP) to implement reliability improvements would have to be funded by the Army in the no warranty alternative. Such improvements would be implemented at no cost to the government in the warranty alternative.

The baseline warranty cost is charged during the first month of the support period. Part of the output of the program is the maximum allowable warranty cost (indifference cost) so it may be unclear why a warranty cost should be part of the input. It is not strictly necessary and, in fact, any figure can be entered by the user, even zero. However, this figure should represent the best estimate of the warranty cost from other sources in order to provide baseline results.

The costs for the no warranty alternative are computed in a way analogous to that for the warranty costs and will not be discussed in detail.

3.4 GOVERNMENT COST FRACTION

The government cost fraction (GCFM(M)) used in the above computations is the expected fraction of repair costs that are borne by the government during month M for the warranty alternative. To determine this quantity for month M the following sequence of computations must be performed.

First, the expected fraction of repair cost borne by the government during month M for engines delivered during month N, N=1, ..., M, must be determined. This is determined from the following equations.

$$AOH(M) = OHM(M)/NEM(M)$$

$$COH(N,M) = COH(N,M-1) + AOH(M);\ N = 1, \ldots, M$$

$$A_n = COH(N,M-1)$$

$$B_n = COH(N,M)$$

$$GCF(N,M) = \left(\int_{A_n}^{B_n} [1-C(X)]\, dx \right) / AOH(M);\ N = 1, \ldots, M$$

where

AOH(M) = The average operating hours per engine during month M.

COH(N,M) = The average cumulative operating hours at the end of month M of engines delivered during month N.

GCF(N,M)* = The average fraction of repair cost borne by the government for a failure during month M by an engine delivered during month N.

C(X) = The fraction of repair cost borne by the contractor when an engine fails at X operating hours. Figure 1 is the curve used for the T-700 engine.

The above method of determing GCF(N,M) is valid under the assumption that during month M the MTBRDR of an engine is exponentially distributed with mean CFR(M).

Next the distribution function of engine age must be updated. If new production engines are delivered during month M (NPE(M)≠0), then the following equations are used.

$$F(N,M) = F(N,M-1)/[1 + NPE(M)/NEM(M-1)]$$

$$F(M,M) = NPE(M)/NEM(M)$$

where

F(N,M) = Fraction of total engine inventory of month M that was delivered during month N.

If NPE(M) = 0 then

$$F(N,M) = F(N,M-1) \; ; \; N = 1, \ldots, M-1$$

$$F(M,M) = 0$$

The Government Cost Fraction can then be determined from the following equation.

$$CGFM(M) = \sum_{N=1}^{M} GCF(N,M) \times F(N,M)$$

4. OUTPUT

For a single reliability improvement the model provides the following output.

1. Operational summary
2. Economic summary
3. Graphic display of no warranty and warranty life cycle cost
4. Indifference costs for various economic lifes.

4.1 The operational summary provides a monthly listing of the fleet size, the engine inventory size, the monthly and cumulative flying hours, failures for both the no warranty and warranty alternatives and, finally, the composite MTBRDR of the engine for both the no warranty and warranty alternative. This summary is not strictly necessary for an economic analysis but is provided because it provides the analyst insight into the dynamics of the simulation and also assists in locating input errors.

4.2 The economic summary provides a monthly listing of the monthly and cumulative costs of both the no warranty and warranty alternatives. The month that the breakeven occurs is also flagged in this printout. A monthly breakdown of the life cycle costs is not strictly necessary, of course, as the quantity of interest is the difference in total life

cycle costs between the two alternatives. However, as in the case with the operational summary, such a monthly record provides insight into the dynamics of the simulation and assists in locating errors in input.

4.3 The graphic display plots the cumulative no warranty and warranty costs against total engine operating hours and against time.

4.4 The indifference cost is computed for various economic lifes. The economic life of the warranty starts at the beginning of the contractor support period and its length is somewhat arbitrary, depending on the analyst's opinion of what a reasonable economic life is. It can extend to the end of the engine's life cycle. The lengths of the economic lifes chosen by the model for indifference cost analysis start at one year and are incremented by a year until the end of the study period is reached.

FIGURE 1

T700 ENGINE WARRANTY PROGRAM

CLAIMS	G.E.	ARMY
200 HOURS	100%	---
300 HOURS	80%	20%
500 HOURS	---	100%

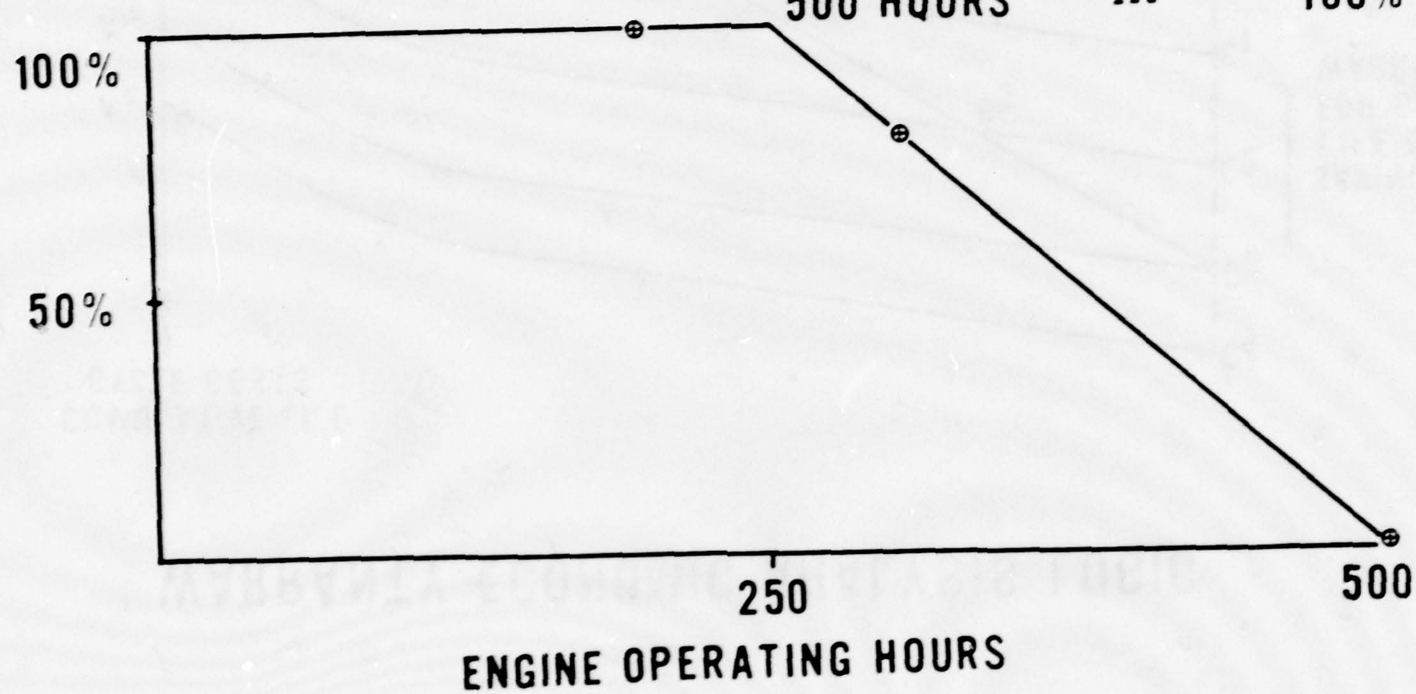


FIGURE 2

WARRANTY ECONOMIC ANALYSIS LOGIC

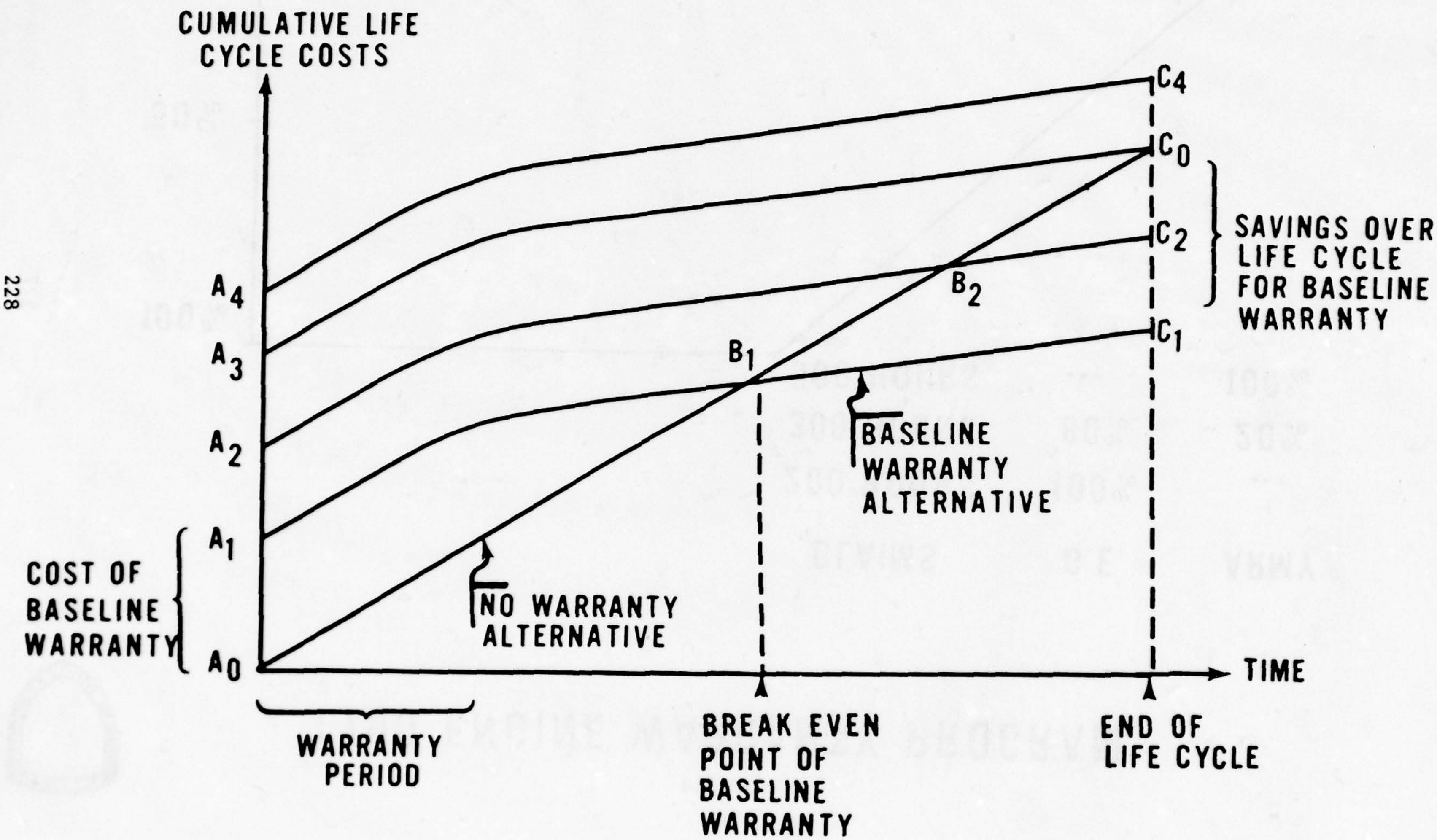


FIGURE 3

IMPACT OF VARIATIONS IN RELIABILITY IMPROVEMENTS

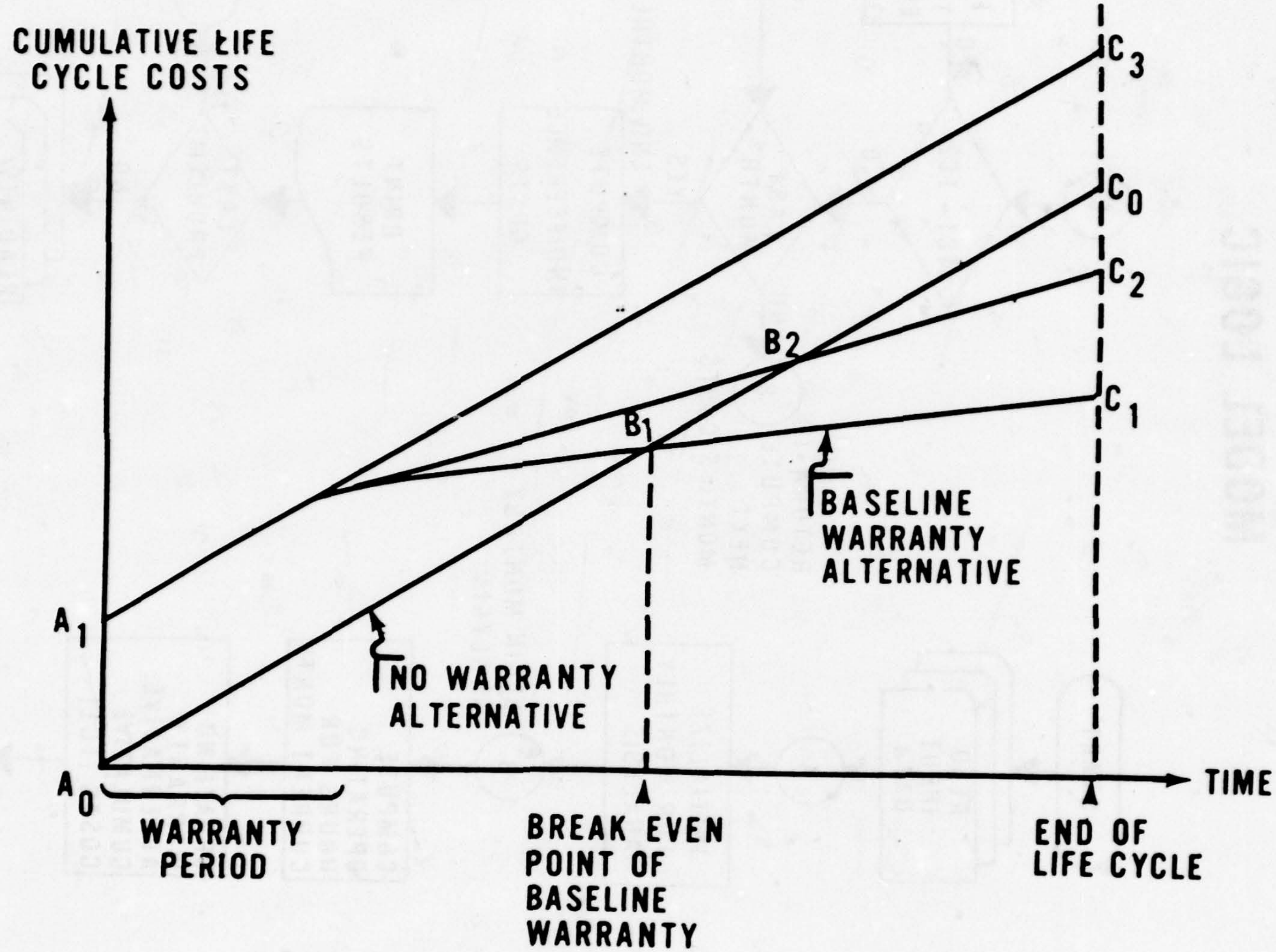


FIGURE 4

MODEL LOGIC

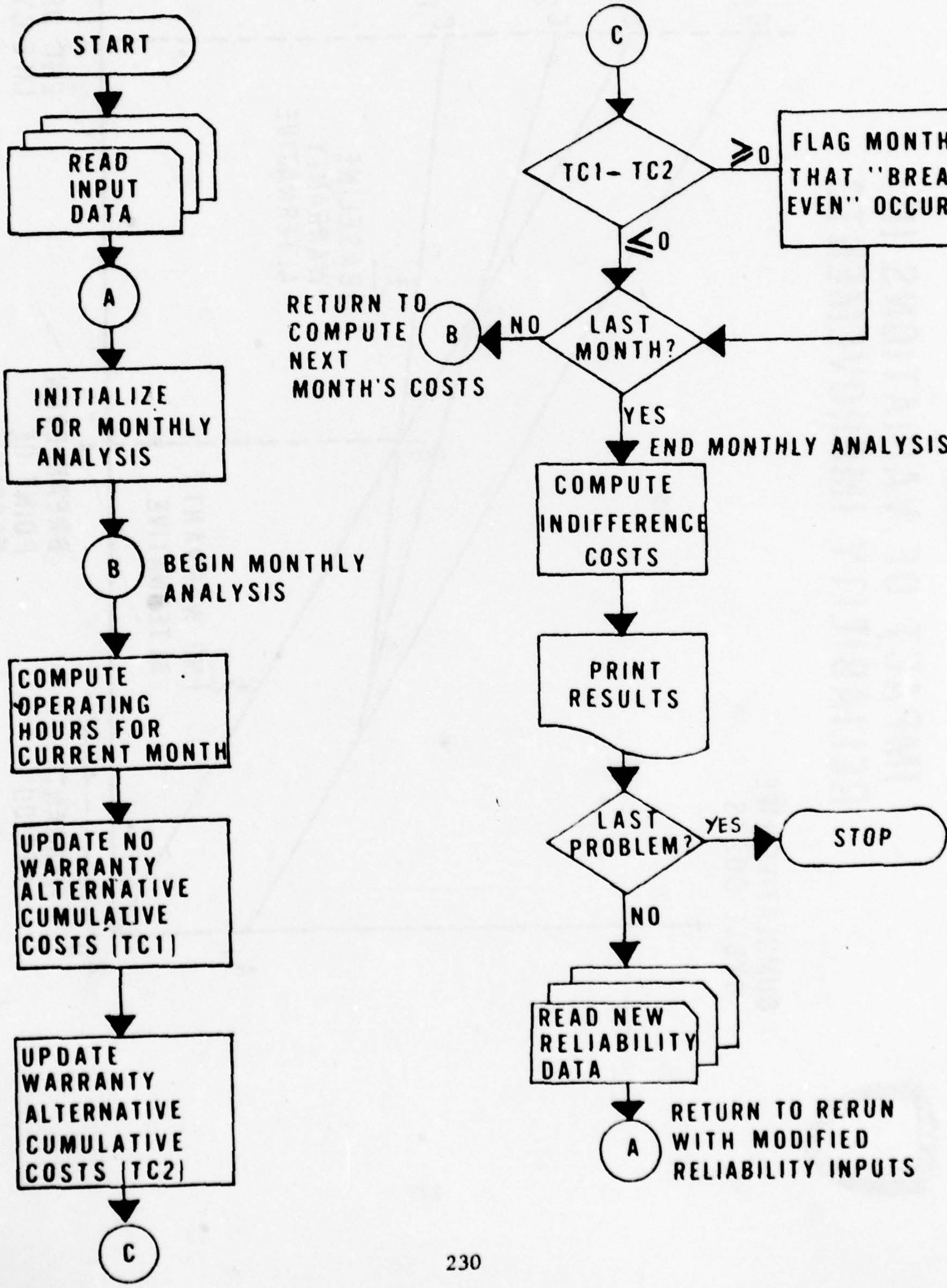
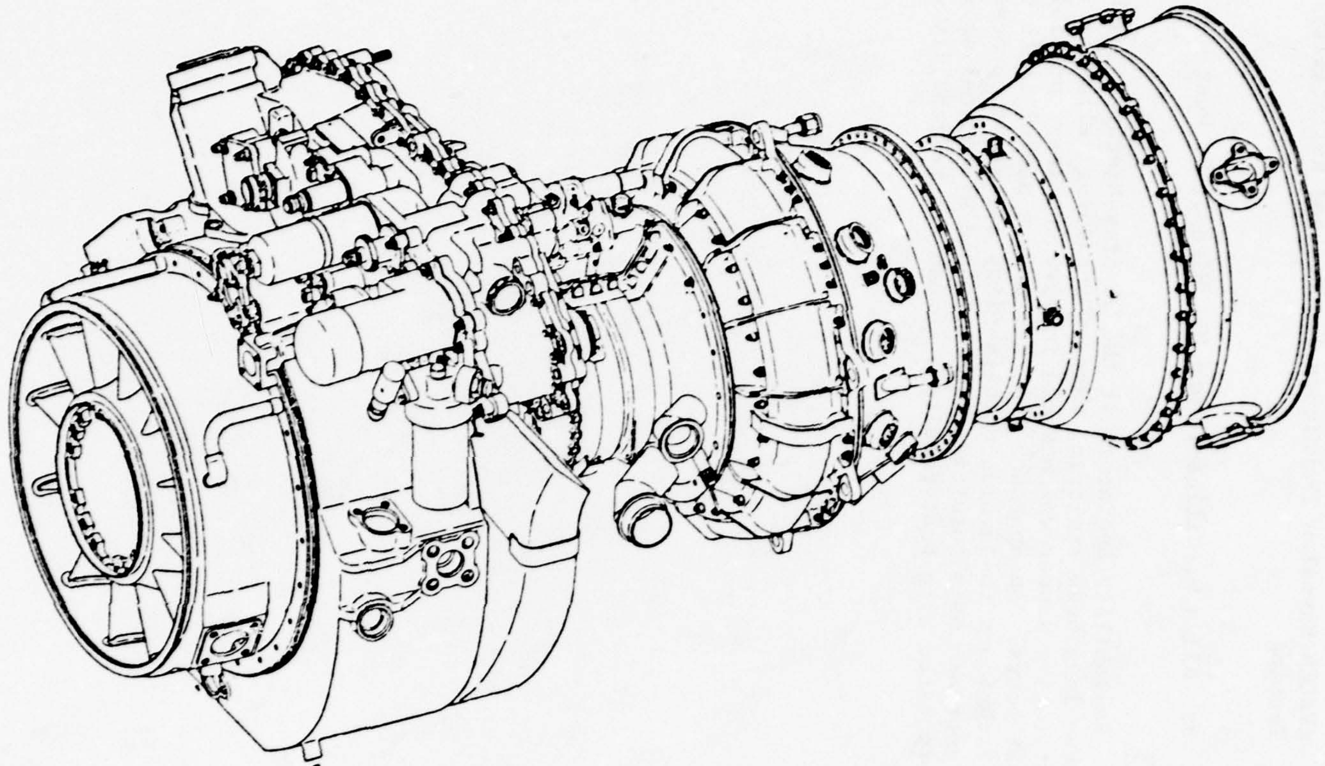


FIGURE 5



T700-GE-700 ENGINE

TITLE: AVSCOM Bayesian Techniques for Reduced Reliability Assurance Testing

AUTHORS: Mr. Allan W. Gillespie and Mr. Michael P. West

ABSTRACT: Reliability Engineers at the US Army Research and Development Command have long been exploring ways of obtaining reliability estimates in a quantitative manner which would involve the least possible amount of flight test hours. An approach that has proven useful is to utilize Bayesian Techniques to develop a reliability assessment procedure. A Bayesian approach uses intuitive judgement and historical maintenance data incorporated with test results to produce a reliability estimate.

INTRODUCTION

For the past decade, the reliability engineer has been constantly seeking methods to estimate the mean-time-between-failure (MTBF) of an aircraft as accurately as possible. The ability to come up with reasonable estimates of reliability is sometimes hampered by the fact that some development programs make no formal reliability provisioning. In many of these situations, the reliability engineer may have an intuitive feeling as to the ability of the system to meet certain reliability goals, based on past performance data on similar designs.

Although currently used methods yield reasonably accurate results, they require a great deal of extremely costly flight test data. In an age where Life Cycle Cost is a prime concern, it is imperative that reliability data be obtained with a minimum amount of test hours.

The most recent attempt to meet the need for such a program is documented in [2]. This approach yields accurate MTBF's yet requires fewer test hours. It combines the data from flight test, prior analyses and the use of bayesian statistical techniques.

BASIC METHODOLOGY

Reliability Assessment during the early period of development is traditionally based on engineering judgement. Traditional assessment methods are not adequate when only a small amount of data is available. For that reason we have gone to the use of Baye's Theorem which allows us to assess achieved reliability with minimum amount of test data.

The mathematics for calculating the reliability numbers in this program differs depending on the input data. This section will describe the basic mathematical concepts used for these calculations.

NOTATION

β	A test result
$f(t)$	Time to Fail (probability density of t)
m	Test data sample size
n	Prior data sample size
$P(\Theta)$	Probability distribution, non-redundant items
$P(\Theta_j)$	Prior probability distribution of Θ_j
$P(\Theta_j \mid B)$	Posterior probability distribution of Θ_j
r	Number of failures
$R(t)$	Reliability of an item at time t
t_x	Time of x-th failure
t_r	Time of r-th failure
T	Total test hours
T_x	Total time for failed items
x	Variable
x_o	Mode
α	Exponent determined by slope
Θ(MTBF)	Mean-time-between-failures/Mean-time-to-fail
Θ_L	Lowest possible value of Θ
Θ_O	Most likely value of Θ

Θ_H	Highest possible value of Θ
$\hat{\Theta}$	Discrete values of Θ_j
$\lambda(t)$	Failure rate

BAYES THEORY

If $\Theta_1, \Theta_2, \ldots\ldots, \Theta_n$ are mutually exclusive events of which one must occur, that is

$$\sum_{r=1}^{n} P_R(\Theta_r) = 1 \quad \text{then}$$

$$P_R(\Theta_r|B) = \frac{P_R(\Theta_r)\, P_R(B|\Theta_r)}{\sum_{r=1}^{n} P_R(\Theta_r) P_R(B|\Theta_r)} \quad \text{for } r-1,2,\ldots\ldots,n \tag{1}$$

This rule yields the probability that the "effect" B was "caused" by the event Θ_r. The probabilities $P_R(\Theta_r)$ are called the "prior" or "a priori" probabilities, and $P_R(\Theta_r|B)$ is called the posterior probability distribution of Θ_r. After the prior probability distribution of MTBF is established and some test data is available, (1) can be used to calculate the Bayes or posterior probability distribution of Θ_r.

COMPUTER CODE

The computer program used in this Bayesian approach provides estimates of the MTBF, reliability and cost of each component of the aircraft system. This information is also provided for those components which affect mission success and flight safety.

A component-by-component review is made to estimate the probability of which component will be the first to fail. Provisions are also included for components with redundant or backup capabilities.

INPUT DATA

The program requires two categories of input data. The first includes information from previous results, engineering judgement and experience. This is termed "prior data." The second is that of "test data" associated with each component, and is derived from flight test hours.

Prior Data

Various types of prior data may be used. Eight such classifications are defined in Table 1.

No Data P1. The first class is that in which no information is available. For some developmental systems, it may not be possible to obtain any prior knowledge either by estimate or results for similar components. For these components only experimental results are subsequently used in seeking Bayesian estimates.

Beta P2. Occasionally, it is advantageous not to spell out the probability distribution of Θ. Instead, the user may be more confident in stating certain characteristics of the distribution from which estimates of $P(\Theta)$ can be generated. The beta probability distribution is employed here, and uses three particular estimates of Θ:

Θ_L = lowest possible value of Θ

Θ_O = most likely value of Θ

Θ_H = highest possible value of Θ

The Beta probability distribution is a two parameter distribution (α,β) that can take many different shapes depending on the value of α and β. For this study it was decided that nineteen combinations of α and β would be sufficient.

These are:

$$\alpha = 1,2,....,10 \quad \text{with } \beta = 10$$

and

$$\beta = 1,2,....,9 \quad \text{with } \alpha = 10$$

For the particular case where $\alpha = \beta = 10$, a distribution very close to normal will result.

In a standard Beta distribution with probability density as shown below, the variable (x) ranges as:

$$f(x) = \begin{cases} k.x^{\alpha-1}\,(1-x)^{\beta-1} & \text{for } 0<x<1 \\ 0 & \text{elsewhere} \end{cases} \qquad (2)$$

The most likely value or mode (x_o) is obtained by maximizing the p.d.f. which gives:

$$x_o = \frac{\alpha - 1}{\alpha + \beta - 2} \quad (3)$$

The mode can also be calculated from

$$x_o = \frac{\Theta_O - \Theta_L}{\Theta_H - \Theta_L} \quad (4)$$

The mode is first calculated from (4). Then (3) is used by substituting values (shown below) in order to determine the α and β that give the closest result to (4).

Example 1:

Suppose $\Theta_L = 10$, $\Theta_O = 30$ and $\Theta_H = 130$

Substitution in (4) yields

$$x_o = \frac{30 - 10}{130 - 10} = .167$$

Now using (3), it is seen that $\alpha = 3$, $\beta = 10$ gives the closest value for x_o, i.e.,

$$x_o = \frac{3 - 1}{3 + 10 - 2} = .182$$

After selecting the appropriate α & β, the probability distribution of x is now found using

$$\Theta = \Theta_L + (\Theta_H - \Theta_L)x, \qquad \text{for } 0 \leq x \leq 1 \quad (5)$$

At this point it is possible to apply (1) and obtain the posterior probability distribution of Θ_r.

Small Samples (Prior and Test). The most general class includes the case in which n units of the item have previously been tested and r units of these failed at known test times. With these values, $P(\Theta)$ can be estimated and used as the prior probability distribution. The particular distribution depends on whether the test is conducted with or without replacement of the failed sample. It also depends on whether the test is terminated due to the number of failures or the total test time.

As shown in [3] the average value of MTBF ($\hat{\Theta}$) is:

$$\hat{\Theta}_{r,n} = \frac{T_{1,n} + T_{2,n} + \ldots\ldots + T_{r,n} + (n-r)T_{r,n}}{r} \quad (6)$$

$$\hat{\Theta}_{r,n} = \frac{\text{Total time tested on all units}}{\text{number of failed units}}$$

Tables 1 and 2 show that the number of units which fail is denoted by r for prior data and x for test data.
The determination of a value for T in (6) is different depending again on the form of the input data as shown in Table III.
Also [3] shows that with $\hat{\theta}$ available the probability distribution of θ is obtained from

$$P_R(\theta \leq \theta_\alpha) = \frac{\hat{\theta} \; \chi_\alpha^2 \; (2r)}{2r} = \alpha \tag{7}$$

where χ_α^2 is a chi-square variable with 2r degrees of freedom.

Large Samples (P6)

The χ^2 (r) distribution is defined as the distribution of the sum of the squares of r independent unit normal variables.

$$\chi^2 (r) = \sum_{i=1}^{n} u_i^2 \tag{8}$$

The distribution is different for each value of r, where r represents the number of degrees of freedom. Reference [4] shows that from the Central Limit Theorem, χ^2 (r) is asymptotically normal for large r. Knowing this we can obtain an approximation to the point P from

$$\frac{\chi^2 p \; (r) - r}{\sqrt{2r}} \simeq u_p, \tag{9}$$

where

$$\chi_p^2 \; (r) \simeq r + u_p \sqrt{2r} \tag{10}$$

Substituting (10) in (7) yields

$$P_R(\theta) = \frac{\hat{\theta} \; (r + u_p \sqrt{2r})}{2r} \tag{11}$$

Specified P8. Generally, in using Bayesian Methods, the user specifies a prior probability distribution of θ. This may be determined from past results for similar components or may be based on the best judgement of the user. In any event, values of the probability of θ, $P(\theta)$ is specified as input data.

Test Data. Six classifications are used to denote the various ways in which the results of the test are obtained as shown in Table 2.

CURRENT EXPERIMENTAL DATA (Table II)

The first form occurs when the hours on failed and non-failed items are known along with total test time. Here, m units of the item are tested and from these x fail at known test times.

The second form occurs when failures and total test times are known. Yet the time on each unit is not known.

Mission, Flight Safety, Cost and Redundancies

The final types of inputs pertain to mission success, flight safety, redundancies, cost and mission times. Each component associated with mission success and/or flight safety must be identified. Also, when it is available, the cost corresponding to the components are given as input, and those components with redundancies are listed.

OUTPUT DATA

Given the input previously discussed, several output options are available. These are:

Component.

The output for each component can be obtained as related to MTBF, reliability and cost estimates.

System.

This will furnish MTBF, reliability and cost estimates for the entire system.

Mission Success.

The components related to mission success are specified as a part of the input data. These components are then used to derive MTBF, reliability and cost estimates.

Flight Safety.

Only those components that relate to flight safety are used for the analysis and generate the same output as mentioned above.

The output is printed out first for Item Analysis, then system, Mission and Safety. Each of these groups give the MTBF and its probability for prior, experimental and posterior data. The reliability is also calculated for mission times of one, two and three hours. The System, Mission and Safety analysis also includes a listing of the items probability to be the first to fail.

TABLE I

Summary of Prior Data

	Prior Data Types	Data
P1	No Data	None
P2	Beta	$\Theta_L, \Theta_O, \Theta_H$
P3	Failure limit without replacement	n, r, t_r, T_r
P4	Failure limit with replacement	n, r, t_r
P5	Time limit without replacement	n, r, t_o, t_r
P6	Large Samples	$n, \bar{t}, s$
P7	Specified distribution	$\Theta, P_p\ (\Theta)$
P8	Time limit with replacement	n, r, t_o

TABLE II

Summary of Test Data

	Test Data	Data
T1	No Data	None
T2	Failure Limit with Replacement	m, x, t_x
T3	x Failures m time $(t_x + T_N)$	x, T_x, T_N
T4	Failure limit without replacement	m, x, t_x, T_x
T5	Time limit without replacement	m, x, T_x, t_o
T6	x Failures in time T	x, T

Input Data (Test, Prior)	Determination of T
(T_1, P_1)	T is defined since no data is available
(T_2, P_4)	$T = mtx$ (test) or $T = ntr$ (prior)
$(T_3, \ )$	$T = T_x + T_n$ (test)
(T_4, P_3)	$T = T_x + (m-x)t_x$ (test) or
	$T = T_r + (n-r)t_r$ (prior)
(T_5, P_5)	$T = T_x + (m-x)t_o$ (test) or
	$T = T_r + (n-r)t_o$ (prior)
$(T_6, \ )$	T given
$(\ , P_8)$	$T = nt_o$ (prior)

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BENEFITS TO HELICOPTER USERS WHICH RESULT FROM REDUCTIONS OF WEIGHT, POWER CONSUMPTION AND FAILURE RATE

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INTRODUCTION

Extensive progress in electronic technology has provided the avionics designer with a wide range of choices. Even within the constraint of achieving desired operational functions, choices are available which affect volume, weight, panel space, power consumption, failure rate, time to repair, cost and life cycle cost. Of course, a number of factors affect these choices. Human factors considerations are important in determining panel space. Current technology in multiplexing, computing, integrating and displaying gives some freedom from mechanical and electronic constraints on instrument panel usage and permits more freedom in the placement of equipment. Life cycle cost analysis of the entire aircraft may establish some failure rate goals for individual subsystems, although some arbitrary allocation among subsystems is usually involved. Sometimes failure rate and replacement time goals are established by consideration of overall factors such as schedule reliability, aircraft availability or probability of mission success. Again, however, practical limitations on the effort which can be expended in system analysis may result in some more or less arbitrary allocation of goals among the various subsystems. Certainly, consideration of the life cycle cost of individual equipment has been helpful in attaining better reliability and maintainability in tradeoff with initial cost. In the case of avionics, however, the equipment life cycle cost does not take into account the impact of failures upon the total aircraft operation.

It would be helpful if some economic measure could be derived which would describe the benefit to the total aircraft operation which results from improvement in subsystem characteristics. This could then be combined with the life cycle cost of the individual subsystem in order to make value judgments. It does appear possible to treat the weight, power consumption and failure rate characteristics, and to some extent, the replacement time, in this manner by considering the impact upon fleet capacity.

FLEET CAPACITY

In military applications, the functional capability and available capacity of the fleet are the attributes which have value for deterrent effect or fighting capability. Since we are not dealing with the func-

tional characteristics of the equipment, the available capacity of the fleet and the annual cost for providing this capacity and using it in the normal activities of military units are the aspects of significance to weight, power consumption and failure rate. The mission-available payload of each aircraft is a suitable measure of its capacity for our present purpose. This is a limited resource which is costly and valuable. We always need more than we can provide. In the short term, we might feel that we have excess payload capacity in a particular aircraft. Even in the short term, however, unused payload capacity is tradable for desirable characteristics such as speed, climb rate, service ceiling, maneuverability, hover capability, operating range or longer time on station. In the long term, unused payload capacity can permit additional equipment which can provide new functional capability for the aircraft. In view of changing threats and unmet needs, almost all aircraft can exploit any increase in mission-available payload capacity to good advantage.

WEIGHT

The initial value of one pound of mission-available payload capacity would be the aircraft fly-away value divided by the mission-available payload. Prior to fielding an aircraft, extensive engineering, operational and economic studies are made to find the most economical means to achieve overall goals. These are subjected to intense review within the military and then by Congress. Subsequent retrofits and modifications are justified. The current fly-away value therefore has resulted from serious and responsible efforts to meet the needs at minimum cost. The decision to invest and subsequent economic conditions establish a value on the aircraft, and consequently the value per pound of mission-available payload.

There is also an annual cost to operate and maintain the aircraft which results in an annual cost benefit if the mission-available payload is increased.

In view of the foregoing discussion, we can see that the initial value of one pound of weight reduction is

$$w_i = V_a/L, \tag{1}$$

where V_a is the aircraft fly-away value and L is the mission-available payload. In this context "mission-available" payload is the amount of load capacity which can be devoted to the mission. This includes mission equipment such as sensors, armament and ammunition as well as cargo and passenger payload, where appropriate.

The annual benefit from one pound of weight reduction is

$$w_a = C/L, \tag{2}$$

where C is the annual operating cost of the aircraft. Thus, the total benefit from weight savings, per pound, over an operating life of N years is

$$W = w_i + Nw_a = (V_a + NC)/L. \tag{3}$$

POWER

Reduction of power consumption is also beneficial to aircraft operation. The electrical power system of the aircraft has an initial value which is in part attributable to the needs of the electronic equipment. Further, a portion of the weight of the aircraft electrical power system can be treated in the same way as the equipment weight was treated in the previous section. It is recognized that a small reduction in power requirement will not necessarily result in the selection of a lighter or cheaper aircraft power generation system. In a retrofit program it is unlikely that the power system would be replaced. However, a reduction in the power consumption would make power available for other uses and it is equitable to credit a power consumption reduction with a proportionate share of the power system cost and weight. Accordingly, the initial value of one watt power reduction is taken to be

$$s_i = (V_p + w_i L_p)/P = (V_p + V_a L_p/L)/P, \tag{4}$$

where V_p, L_p and P are the power system value, weight and output power respectively.

There is an annual cost associated with carrying the power system weight and therefore a benefit can be assigned if the power requirement is reduced. The annual benefit assignable to one watt power reduction is

$$s_a = w_a L_p/P = CL_p/LP. \tag{5}$$

The total benefit from a power consumption reduction of one watt is therefore

$$S = s_i + Ns_a = (V_p/P + Va\ L_p/LP) + NCL_p/LP. \tag{6}$$

Again, it should be mentioned that these assignments of value associated with power reduction do not imply that the weight or cost of the power system can be reduced in a particular type aircraft. They are methods of assigning value to the power source. The power made available by reduction may be used to fill other needs. Over a period of time the application of this methodology as an aid to making value judgments relative to a number of equipments should result in significant power savings which would permit the use of smaller power systems.

The additional benefits resulting from reduction of fuel requirements are small compared to the above factors and can be ignored.

These benefits from weight and power consumption reduction are independent of the type of system involved. They are therefore applicable to any aircraft subsystem.

FAILURE RATE

The treatment of the benefit from improvement in the failure rate is more complicated than the weight and power cases. It involves some consideration of the function which the equipment performs, the missions to be expected and the time required for replacement after failure.

There are several consequences from an apparent equipment failure. If the risk of continuing the flight is too high or the functional capability of performing the desired mission has been lost, the pilot would be expected to return to base or to an alternate location. If the circumstances are different, he may elect to continue the mission, perhaps accepting some higher risk or lower mission effectiveness, and perhaps incurring some additional distance flown or increased communication load which might be involved in work-around procedures. In any event, there will be some aircraft down time to fix or change the equipment.

In treating the effect of failures we must recognize that operational costs are dependent upon apparent failures which result in equipment removals, so we shall use the removal rate rather than the failure rate.

The ramp check, removal, replacement and checkout will require some down time. The amount of time depends to some extent upon the nature of the equipment built-in test capability, the convenience of the installation, the amount of manpower devoted to the aircraft maintenance, and the availability of spares. Under prevailing conditions in Army operations this down time is probably in the order of one hour for typical equipments, but this must be estimated in each case. There is obviously some interaction with life cycle costs. If one postulates down times much shorter than one hour, one must assume that spares are stocked in many locations and either in substantial quantities or with streamlined arrangements for repair.

The average annual number of equipment removals per aircraft is

$$m_r = Fr, \tag{7}$$

where F is the aircraft annual flight time and r is the mean removal rate. The average annual down time per aircraft is

$$D_a = dm_r = dFr, \tag{8}$$

where d is the down time per removal. This down time reduces the fleet capacity. The initial cost associated with the lost capacity is

$$R_i = D_aV_a/F = drV_a. \tag{9}$$

In some instances, it might be appropriate to identify a cost per hour of down time, and therefore an annual cost associated with the down time. However, in this case all operating costs have been allocated to the flight time.

If symptoms develop in flight which indicate equipment failure and the mission is aborted without accomplishing its goals, the flight time involved represents a capacity loss as well as an operating cost. Since circumstances vary widely, it is difficult to assign a precise value to these quantities. As an aid to this judgment, a model will be developed which will express the useless flight time as a function of parameters which are of operational significance.

The probability that there will be a failure indication prior to time t after takeoff is

$$P(t) = \int_0^t re^{-rt'}\,dt' = 1 - e^{-rt} \doteq rt \tag{10}$$

Let the average mission duration be T. Assume that if a failure should occur prior to a time kT the mission would be aborted whereas if it occurred after the time kT it would be continued. By equation (10), the probability that a failure will occur prior to time kT and therefore cause the flight to be aborted is rkT. The number of aborted missions per year, N_a, would therefore be the number of missions flown per year (annual flight time per aircraft/T) times this probability for aborting:

$$N_a = (F/T)\,(kTr) = Fkr. \tag{11}$$

In those missions which do abort, the average time from takeoff to failure indication is

$$\bar{t} = \int_0^{kt} tre^{-rt}\,dt \Big/ \int_0^{kt} re^{-rt}\,dt$$

$$= (e^{rkt} - 1 - rkt)/r(e^{rkt} - 1). \tag{12}$$

For small rkt this reduces to

$$\bar{t} \doteq kT/2. \tag{13}$$

Thus, for those cases in which a failure indication occurs prior to the time kT and the flight is aborted without accomplishing its mission, the average duration of the flight up to the time of aborting is kT/2. Assuming an equal time is spent in returning to base or to an alternate location, the total annual useless flight time per aircraft is

$$T_u = 2\,N_a\bar{t} = F\,k^2rT. \tag{14}$$

This useless flight time reduces the capacity of each aircraft, resulting in an initial cost for capacity replacement of

$$u_i = T_u V_a/F = k^2 rTV_a. \tag{15}$$

The corresponding annual operating cost incurred by the useless flight is

$$u_a = T_u (C/F) = k^2 rCT. \tag{16}$$

Over the aircraft life of N years, therefore, the cost of the useless flight time would be

$$U = u_i + Nu_a = k^2 Tr(V_a + NC), \tag{17}$$

and the combined benefit from a unit improvement in removal rate, considering down time and useless flight time, would be

$$R = (d + k^2 T) V_a + Nk^2 TC. \tag{18}$$

The current trend in specifying equipment failure rates is to define them under fairly severe conditions of vibration, temperature and rate of change of temperature in laboratory tests. In many instances, where care is taken in selecting the location for installation, actual true field failure rates are lower than the specified failure rate. On the other hand, field removal rates are significantly higher than the true failure rate. (Marner, 1969) These two effects tend to cancel, so that the specification value of the failure rate is often a good approximation of the removal rate.

In the application of equation (18) one estimates, for each type of mission anticipated, the duration, T, the turn-back ratio, k, and the down time, d, expected under the circumstances, and then forms the weighted average of the benefits according to the distribution of time expected to be spent in each type of mission.

Note that the down time per removal multiplied by the fly-away value of the aircraft is the most important term in the benefit from removal rate improvement in typical helicopters because the mission duration is in the order of one hour and k is typically less than 0.5.

We should note again that the benefit from reliability improvement given by equation (18) does not take into account extra risks and costs associated with completing missions after equipment failure. These appear to be quite sensitive to the type equipment and mission as well as the operating doctrine. In some cases, these factors could contribute significantly.

NUMERICAL ESTIMATES FOR HELICOPTERS

The above analysis was applied to a projected fleet composed of the three CH-47 models, the AH-1S, the UTTAS, and the AAH. The current value of the CH-47's was assumed and only 10 years of useful life, since the modernization program had not been approved. Lifetimes of 15 years for the AH-1S and AAH, and 18 years for the UTTAS were used. The Training and Doctrine Command supplied typical mission projections and the AVSCOM Maintenance Directorate as well as the aircraft Project Offices provided historical data and aircraft life cycle cost models. As a result of this cooperation, it was possible to conduct a reasonably complete numerical evaluation. We found, for this composite fleet, that the benefit, per aircraft, over the life of the aircraft, would be $3000 for a weight reduction of one pound and $70 for a power consumption reduction of one watt. Assuming a down time of one hour per removal, and a turn-back point of 40% of the mission, there was a benefit of $2300 for the reduction of removal rate by one per one thousand hours of operation.

If one prefers to combine these benefits with the initial cost of new equipment rather than with the life cycle cost, present value computations can be used on the annual costs, thus referring them back to the initial time. Assuming an interest credit of 8% per year, then one pound weight reduction would compare with the initial cost at the rate of $1800, one watt would be worth $41 and a removal rate reduction of one per one thousand hours would be worth $2000.

I realize, of course, that these benefits are not the type that can be used to reduce any existing budgets. However, they do speak to the establishment of value judgments which conserve our resources and obtain maximum capability from future investments. If these factors are applied to the improvements which are typically available by applying a new generation of electronics technology, it will be seen that significant benefits are derived. Both AVSCOM and ECOM are beginning to consider these factors as a guide to value judgments.

ACKNOWLEDGMENTS

I would like to thank Mr. John Rottjakob of our office for the considerable effort of organizing and conducting the numerical evaluation, and to Mr. Rottjakob, Mr. Seymour Greenspan of the ECOM Avionics Laboratory and Mr. Harry Cook of the ECOM Combat Surveillance and Target Acquisition Laboratory for stimulating discussions.

REFERENCE

Marner, G. R., 1969, Hybrid Systems for Guidance and Navigation. AGARD Conference Proceedings No. 54, Sep 1969.

TITLE: A Simple Interactive Stochastic Algorithm for a Reliability, Availability and Maintainability (RAM) Policy Guideline of an Airmobile Combat System

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ABSTRACT: The simulation of aircraft reliability, availability, and maintainability is an extremely complex task which deals with details of aircraft missions, scheduling, maintenance, supply, performance, manpower, etc. Implementation of such kind of simulation often requires complex models with laborious input preparation and tedious output digestion.

From the top-level decision makers' point of view, it is often helpful to gain an insight into the overall trend of significant interactions between an aircraft's reliability, availability, and maintainability characteristics so as to formulate overall policy guidelines in anticipation of future behavior. The objective of this paper is to present an interactive algorithm which will facilitate a sensitivity analysis and impact study on such interactions. Computer graphic capability can be built into the program for instantaneous display of interactions.

The algorithm is based on the stochastic modeling concepts of population dynamics, fertility, mortality, and techniques of population projection. The mission-cycle of an aircraft is divided into three overall mission specific stages: (1) maintenance, (2) ready pool, and (3) combat mission. With the inclusion of the average daily utilization, call rate, grounding failures, scheduled maintenance, etc., this algorithm computes an overall guideline for a maintenance policy, aircraft replacement scheduling, readiness improvement, and evaluation or risk factors associated with failure to meet various levels of future operational goals. This algorithm is flexible enough to be adapted to other mobile systems.

AN INTERACTIVE STOCHASTIC ALGORITHM FOR A RELIABILITY, AVAILABILITY AND MAINTAINABILITY (RAM) POLICY GUIDELINE OF AN AIR MOBILE COMBAT SYSTEM

By

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Introduction

The simulation of aircraft reliability, availability, and maintainability (RAM) is an extremely complex task which deals with details of aircraft missions, scheduling, maintenance, supply, performance, manpower, etc. Implementation of such a simulation often requires complex models with laborious input preparation and tedious output digestion.

From the top-level decision makers' point of view, it is often helpful to gain an insight into the overall trend of significant interactions between an aircraft's reliability, availability, and maintainability characteristics so as to formulate overall policy guidelines in anticipation of future behavior. The objective of this paper is to present an interactive algorithm which will facilitate analysis and study of such interactions. Computer graphic capability can be built into the program for instantaneous display of interactions.

The algorithm presented here is based on the mathematical concepts of Markov, state, and renewal processes. In particular, the examples presented are based on Markov chain processes. Although the examples given are models of aircraft fleet operations, the algorithm is flexible enough to be adapted to other operating systems.

Analytical Model Description

The first thing to be considered when modeling a stochastic process is whether the process is dependent or independent. A dependent process is one in which the future value of the process depends at least in part on the past or present value. An independent process is one in which the future value of the process is independent of the past or present. An example of an independent process is a coin toss where the value (heads or tails) of the next toss of the coin does not depend on whether the present value is heads or tails (if the coin toss process is truly random). Obviously, the future state of a fleet of aircraft is not independent of the present state.

When considering a fleet of aircraft (or other operating equipment), we cannot say that the present condition of the fleet is independent of the past. We can say, however, that the future condition of the fleet is dependent only on the present; i.e., it does not matter how the fleet arrives at its present condition. Given the present condition, the only thing that now matters is what decisions are made affecting that condition. This idea can be expressed mathematically through the concept of a Markov process. A model based on this idea was suggested by Law (Reference 1). In this paper, the application of such a model is considered.

The value or condition of a system can be expressed as a state vector containing n states:

(1) condition of system = $S\ (s_1, s_2, s_3, \ldots, s_n)$

If the system is in state s_i, the probability that it will be in state s_j in the future is p_{ij}; that is,

(2) $s_j = p_{ij} s_j$

This probability is usually called a "transition" probability because it describes how the system gets to state s_j from state s_i. It can also be considered as a description of the decision that takes the system from state s_i to state s_j.

Now if we consider the condition of the system to be described by the state vector (1) above containing n states, we see that it takes n^2 transition probabilities to describe the transition from the n current states to the n states that describe some future condition of the system. This can be expressed in matrix form as:

$$(3) \quad \begin{bmatrix} s_1 \\ s_2 \\ \cdot \\ \cdot \\ \cdot \\ s_n \end{bmatrix} = \begin{vmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & & \\ \cdot & & & \\ \cdot & & & \\ \cdot & & & \\ p_{n1} & & & p_{nn} \end{vmatrix} \begin{bmatrix} s_1 \\ s_2 \\ \cdot \\ \cdot \\ \cdot \\ s_n \end{bmatrix}$$

(4) $S_m = PS_k$

If the next value of the system depends only on the present value, that is, if $m = k + 1$, then (3) describes a Markov process. The $n \times n$ matrix containing the transition probabilities is called the transition matrix. When the value of the system changes in a series of discrete trials, the process is called a Markov chain process.

It can now be seen that if the condition of a system can be described in terms of a finite number of states and if the stipulation that the future depends only on the present is acceptable, then the condition of the system can be modeled using a Markov process. However, it is not always appropriate to say that the future depends only on the present, but is also dependent on some past decision or action. There are a number of ways to handle this type of situation using the general form (3) above (see Reference 1, for example), but we will not discuss them here.

It is appropriate at this point to mention some properties of Markov processes that are useful in model building. We have stated that (3) represents a Markov process. We require then that the matrix P be a regular stochastic matrix; that is, the sum of the elements in each column of the matrix must equal 1 and P, or some power of P, must contain only positive elements. Then the following theorems are true (cf. Reference 2):

(a) P has a unique fixed probability vector v with positive components.

(b) The sequence P, P^2, P^3,..., approaches the matrix T whose rows are each the fixed point v.

(c) If p is a probability vector, then the sequence of vector p^P, p^{P^2}, p^{P^3}..., approaches the fixed point v.

(d) If $p = \{ Pi \}$ is the probability distribution of the system at some arbitrary time, then p^P is the probability distribution of the system one step later and p^{P^n} is the probability distribution of the system n steps later.

(e) In the long run, the probability that state s_{in} occurs is approximately equal to the component v(j) of the unique fixed probability vector v of P.

Model Development

Historical data for an operating system is usually recorded in terms of the amount of time that the system is in various states of readiness or operability. Consider, for example, a black box with one input and one output. At various times something is input to the black box. Whether or not a corresponding output occurs depends on the condition of the black box. Now assume that the information recorded for this black box indicates only times that the system was fixed or broken. The state vector for the black box then is

(5) condition of black box = S (fixed, broken)

The transition matrix, where Pr indicates probability, is

$$(6) \quad \begin{vmatrix} \text{Pr (remaining fixed)} & \text{1 - Pr (remaining broken)} \\ \text{1 - Pr (remaining fixed)} & \text{Pr (remaining broken)} \end{vmatrix}$$

This model gives the probabilities that the next time an input is applied an output will be received, given the current condition of the black box. This implies that we will continue to operate the black box in the way in which it was operated in the past. However, if the black box will behave differently if operated differently, then the model is not adequate.

Now consider the black box to be a fleet of aircraft. Since the condition of the fleet depends on the utilization rate of the aircraft, the model must allow for a variable utilization rate. To do this, the state "fixed" can be divided into two states: "fixed but not flying" and "fixed but flying." To use more appropriate terminology, let us call these states "ready pool" and "mission." The "broken" state we will call "maintenance." The values of these states at any given time will then indicate the percentage of the fleet expected to be in each state at that time. The transition matrix for this model is:

$$(7) \quad \begin{vmatrix} \text{Pr (stay in ready pool)} & \text{Pr (mission to ready pool)} & \text{Pr (maintenance to ready pool)} \\ \text{Pr (ready pool to mission)} & \text{Pr (continue flying)} & \text{Pr (maintenance to mission)} \\ \text{Pr (ready pool to maintenance)} & \text{Pr (mission to maintenance)} & \text{Pr (stay in maintenance)} \end{vmatrix}$$

The next step in building the model is to determine what the transition probabilities are. The best way to start is to decide which of the probabilities are not needed. In building this model, let us decide not to allow an aircraft to fly immediately after leaving maintenance; that is,

Pr (maintenance to mission) = 0

Let us also decide not to allow an aircraft to go to maintenance directly from the ready pool; that is,

Pr (ready pool to maintenance) = 0

Now if we further decide to examine the process in fixed time steps equal to the average length of the mission and we choose the length of all missions to be equal to the average mission length, then

Pr (continue flying) = 0

We can use an exponential distribution to represent the probability that an aircraft will enter maintenance:

Pr (mission to maintenance) = $1 - \exp(-\lambda_d t_c)$

where λ_d is the rate at which aircraft enter maintenance and t_c is the length of the cycle. Since (7) is a regular stochastic matrix, it follows that

Pr (mission to ready pool) = 1 - Pr (mission to maintenance)

Similarly, we can use the exponential distribution to represent the probability that an aircraft will be called to fly a mission, and the probability that an aircraft will leave maintenance. This gives:

Pr (stay in ready pool) = $\exp(-\lambda_f t_c)$

Pr (ready pool to mission) = $1 - \exp(-\lambda_f t_c)$

Pr (stay in maintenance) = $\exp(-\lambda_m t_c)$

Pr (maintenance to ready pool) = $1 - \exp(-\lambda_m t_c)$

Where λ_f is the rate at which aircraft are called to fly and λ_m is the rate at which aircraft leave maintenance.

The transition matrix for this model now becomes:

$$(8) \quad \begin{vmatrix} \exp(-\lambda_f t_c) & \exp(-\lambda_d t_c) & 1 - \exp(-\lambda_m t_c) \\ 1 - \exp(-\lambda_f t_c) & 0 & 0 \\ 0 & 1 - \exp(-\lambda_d t_c) & \exp(-\lambda_m t_c) \end{vmatrix}$$

Now that we have defined the transition matrix, we can take advantage of the properties of the Markov process to determine the condition of the fleet. The properties given above imply that if we start from any arbitrary condition and examine n time steps of the model, then as n approaches infinity, the model will converge to an equilibrium condition. This equilibrium condition is defined by the unique fixed probability vector v of the transition matrix P. We wish to find the current condition of the fleet based on the transition matrix P given in (8) which was defined from our knowledge of the characteristics of fleet operation. The current condition of the fleet is defined by the state vector S which we know from property (e) above is equal to the fixed probability vector v of our transition matrix. Since we know that we can find S eventually by starting with any arbitrary vector S', we can take a shortcut by starting from S' = S. This gives

$$(9) \qquad S = PS$$

or expressing (9) in matrix form and performing the required multiplication, we obtain the set of simultaneous equations

$$s_1 = s_1 \cdot \exp(-\lambda_f t_c) + s_2 \cdot \exp(-\lambda_d t_c) + s_3 \cdot (1-\exp(-\lambda_m t_c))$$

$$(10) \qquad s_2 = s_1 \cdot (1-\exp(-\lambda_f t_c)$$

$$s_3 = s_2 \cdot (1-\exp(-\lambda_d t_c)) + s_3 \cdot \exp(-\lambda_m t_c)$$

In addition, from the definition of the Markov process, we have

$$(11) \qquad s_1 + s_2 + s_3 = 1$$

Now we can find the individual states s_1, s_2 and s_3 that define the current condition of the fleet S by solving equations (10) and (11). This gives:

$$s_1 = (1-\exp(-\lambda_m t_c))/D$$

$$(12) \qquad s_2 = (1-\exp(-\lambda_m t_c))(1-\exp(-\lambda_f t_c))/D$$

$$s_3 = (1-\exp(-\lambda_f t_c))(1-\exp(-\lambda_d t_c))/D$$

where

$$(13) \qquad D = (1-\exp(-\lambda_m t_c)) + (1-\exp(-\lambda_m t_c))(1-\exp(-\lambda_f t_c) + (1-\exp(-\lambda_f t_c))(1-\exp(-\lambda_d t_c))$$

Of course it is quite possible to build models containing more than 3 stages. It may be desirable, for example, to divide the maintenance stage into two stages: scheduled and unscheduled maintenance. It may be desirable to separate NORS (Not Operationally Ready Supply) from maintenance. It may even be desirable to include scheduled and unscheduled maintenance and NORS in a five stage model. In fact, the number of stages is limited only by one's imagination and ability to define the transition probabilities.

Programming the Model

It should be apparent from the analytical description of the Markov process above that a general model accommodating any specified number of stages can easily be programmed. A flow chart of such a model is given as Figure 1. This program is built around two subroutines, TRANS and CYCLE. Subroutine TRANS defines the elements of the transition matrix while subroutine CYCLE determines the next state vector from the current one. A FORTRAN listing of CYCLE is given in Figure 2 and a listing of TRANS for the 3 stage model above is given in Figure 3. The flow chart in Figure 1 allows for modeling both stationary and nonstationary processes. A stationary process is one in which the transition matrix remains constant while a nonstationary process is one in which the transition probabilities are functions of time.

Model Application

Now let us apply the model to a real system. The data in Table I gives the average condition of a helicopter fleet in 1971. A 3 stage model can be built from this data using the transition matrix given above as (8). The required parameters are computed as follows:

i. rate at which aircraft enter maintenance, λ_d:

$$\lambda_d = 1.0 \ / \ (\text{mean time between maintenance})$$

$$= 1.0 \ / \ 1.35$$

$$= 0.74074074$$

ii. rate at which aircraft are called to fly, λ_f:

$$\lambda_f = (\text{no. flights}) \ / \ (\text{no. aircraft x available flying hours})$$

$$= 2{,}917{,}955 \ / \ (2526 \times 3650)$$

$$= 0.31648445$$

iii. rate at which aircraft leave maintenance, λ_m:

$$\lambda_m = 1.0 \ / \ (\text{mean elapsed maintenance time})$$

$$= 1.0 \ / \ 5.3$$

$$= 0.18867925$$

iv. average flight length, t_c:

$$t_c = (\text{no. flight hours}) \ / \ (\text{no. flights})$$

$$= 1{,}096{,}510 \ / \ 2{,}917{,}955$$

$$= 0.3757803$$

If we define availability in this model as being the probability that an aircraft is either in the ready pool stage or in the mission stage, then

(14) availability = $s_1 + s_2$

Substituting the values computed above into (12) and (13) gives a value for availability of 73.634%. Figure 4 shows graphic output from the computer program for the 3 stage model. The program started with an arbitrary state vector, and after 100 cycles had converged to the state vector $s_1 = 0.6622$, $s_2 = 0.07425$, $s_3 = 0.26355$ giving an availability of 73.645%.

We can go one step further and build a model with 4 stages by splitting the maintenance stage to give a scheduled maintenance stage and an unscheduled maintenance stage. The transition matrix for this model is shown in Figure 5. Definition of the probabilities is given in Table II. The parameters required for this model are computed as follows:

i. rate at which aircraft are called to fly, λ_1:

λ_1 = (no. flights) / (no. aircraft x available hours)

= 0.31648445

ii. rate at which aircraft enter scheduled maintenance, λ_2:

λ_2 = 1.0 / (mean time between scheduled maintenance)

= 1.0 / 2.749

= 0.36376864

iii. rate at which aircraft enter unscheduled maintenance, λ_3:

λ_3 = 1.0 / (mean time between unscheduled maintenance)

= 1.0 / 2.652

= 0.37707391

iv. rate at which aircraft leave scheduled maintenance, λ_4:

λ_4 = 1.0 / (mean elapsed scheduled maintenance time)

= 1.0 / 5.40

= 0.18518519

v. rate at which aircraft leave unscheduled maintenance, δ_5:

$$\delta_5 = 1.0 \; / \; \text{(mean time between unscheduled maintenance)}$$

$$= 1.0 \; / \; 5.195$$

$$= 0.19249278$$

vi. average length of mission, t_c:

$$t_c = \text{(no. flight hours)} \; / \; \text{(no. flights)}$$

$$= 0.3757803$$

Graphic output from the program for this model is shown in Figure 6. The availability computed by the program for this model is 72.335%.

In similar fashion, models containing any desired number of stages can be built. Figure 7 shows graphic output for a 5 stage model where the unscheduled maintenance stage has been split into a NORM (Not Operationally Ready Maintenance) and a NORS (Not Operationally Ready Supply) stage. The availability computed by the program for this model is 70.265%. Figure 8 shows the 5 stage model used to investigate the effect of a change in scheduled maintenance rate on availability of the fleet. The rate at which aircraft enter scheduled maintenance was changed to 0.18188432 (from 0.36376864 used above) resulting in an availability of 76.185%.

Conclusions

In this paper we have demonstrated the application of Markov chain processes to analysis of reliability, availability and maintainability policies. A computational algorithm was presented and applied to a real world situation. The algorithm is flexible, easily programmed, and can be made interactive. The model presented here is not intended to replace simulation models, but can be used to gain insight into trends which would result from overall policy changes.

References

1. Law, Harold Y. H., "A Macroscopic Concept for Modeling Logistic Policy Guideline of an Airmobile Combat System," presented at the 15th US Army Operations Research Symposium, Ft Lee, VA, 26-29 October 1976.

2. Feller, William, An Introduction to Probability Theory and Its Applications, Volume I, third edition, John Wiley & Sons, Inc, New York, 1970

Table I. Condition of a Helicopter Fleet (Averaged Over a One Year Period)

Fleet availability - 74.0%
Fleet NORM - 16%
Fleet NORS - 10%

Average inventory - 2526 aircraft
Total flight hours - 1,096,510
Total flights - 2,917,955

Mean time between scheduled maintenance - 2.749 hours
Mean time between unscheduled maintenance - 2.652 hours
Mean time between all maintenance - 1.35 hours

Mean elapsed scheduled maintenance time - 5.40 hours
Mean elapsed unscheduled maintenance time - 5.195 hours
Mean elapsed maintenance time (all maintenance) - 5.30 hours

Table II. Definition of Transition Probabilities for Four Stage Model

1.	$p_{11} = \exp(-\lambda_1 t_c)$	Pr (stay in ready pool)
2.	$p_{21} = 1 - p_{11}$	Pr (ready pool to mission)
3.	$p_{31} = 0.0$	Pr (ready pool to scheduled maintenance)
4.	$p_{41} = 0.0$	Pr (ready pool to unscheduled maintenance)
5.	$p_{12} = \exp(-\lambda_2 t_c - \lambda_3 t_c) - p_{32}p_{42}$	Pr (mission to ready pool)
6.	$p_{22} = 0.0$	Pr (continue flying)
7.	$p_{32} = 1 - \exp(-\lambda_2 t_c)$	Pr (mission to scheduled maintenance)
8.	$p_{42} = 1 - \exp(-\lambda_3 t_c)$	Pr (mission to unscheduled maintenance)
9.	$p_{13} = 1 - \exp(-\lambda_4 t_c)$	Pr (scheduled maintenance to ready pool)
10.	$p_{23} = 0.0$	Pr (scheduled maintenance to mission)
11.	$p_{33} = \exp(-\lambda_4 t_c)$	Pr (stay in scheduled maintenance)
12.	$p_{43} = 0.0$	Pr (scheduled maintenance to unscheduled maintenance)
13.	$p_{14} = 1 - \exp(-\lambda_5 t_c)$	Pr (unscheduled maintenance to ready pool)
14.	$p_{24} = 0.0$	Pr (unscheduled maintenance to mission)
15.	$p_{34} = 0.0$	Pr (unscheduled maintenance to scheduled maintenance)
16.	$p_{44} = \exp(-\lambda_5 t_c)$	Pr (stay in unscheduled maintenance)

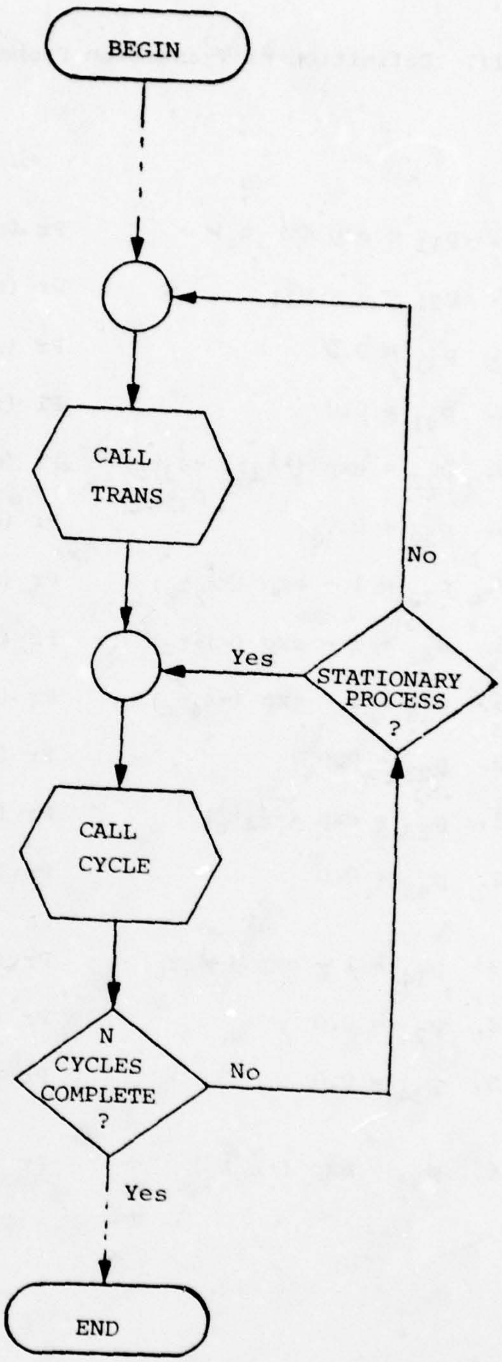

Figure 1. Flow chart for general state model of an operating system

```
      SUBROUTINE CYCLE(S,T,V,N,NSQ,S1,IERR)
      DIMENSION S(N),T(NSQ),V(N),S1(N)
C**** DEFINITIONS:
C****
C**** S - STATE VECTOR (LAST CYCLE)
C**** S1 - STATE VECTOR (PRESENT CYCLE)
C**** T - TRANSITION MATRIX
C**** V - TRANSIENT COMPONENT MATRIX
C****
C**** CHECK TRANSITION MATRIX
C****
C**** ON RETURN:
C**** IERR = 0 MEANS NO ERRORS
C**** IERR = 1 MEANS ONE OR MORE ELEMENTS OF TRANSITION MATRIX
C****         ARE EITHER >1.0 OR <0.0
C**** IERR = 2 MEANS ONE OR MORE COLUMNS OF TRANSITION MATRIX
C****         ARE >1.0
C****
      IERR=0
      DO 10500 J=1,N
      TT=0.0
      JM1=(J-1)*N
      DO 10200 I=1,N
      K=I+JM1
      TT=TT+T(K)
      IF (T(K)-1.0) 10100,10200,10400
10100 IF (T(K)) 10400,10200,10200
10200 CONTINUE
      IF (TT-1.0) 10300,10600,10300
10300 IERR=1
10400 IERR=IERR+1
      GO TO 10600
10500 CONTINUE
C**** END ERROR CHECK
C****
C**** BEGIN COMPUTATION OF STATE VECTOR FOR CURRENT CYCLE
C****
10600 CONTINUE
      DO 20100 I=1,N
      S1(I)=V(I)
      DO 20100 J=1,N
      K=I+(J-1)*N
20100 S1(I)=S1(I)+S(J)*T(K)
      RETURN
      END
```

Figure 2. Listing of subroutine CYCLE

```
      SUBROUTINE TRANS
      COMMON S1(5),S2(5),P(25),V(5),RATE(10),ADU,
     *IY,IAL,NCY,NS,TIME,S(100,6),SMAX,FD,TTIME,
     *S0(5),TAU
      P(2)=1.0-EXP(-RATE(2)*TIME)
      P(1)=1.0-P(2)
      P(6)=1.0-EXP(-RATE(6)*TIME)
      P(4)=1.0-P(6)
      P(7)=1.0-EXP(-RATE(7)*TIME)
      P(9)=1.0-P(7)
      RETURN
      END
```

Figure 3. Listing of subroutine TRANS for three stage model

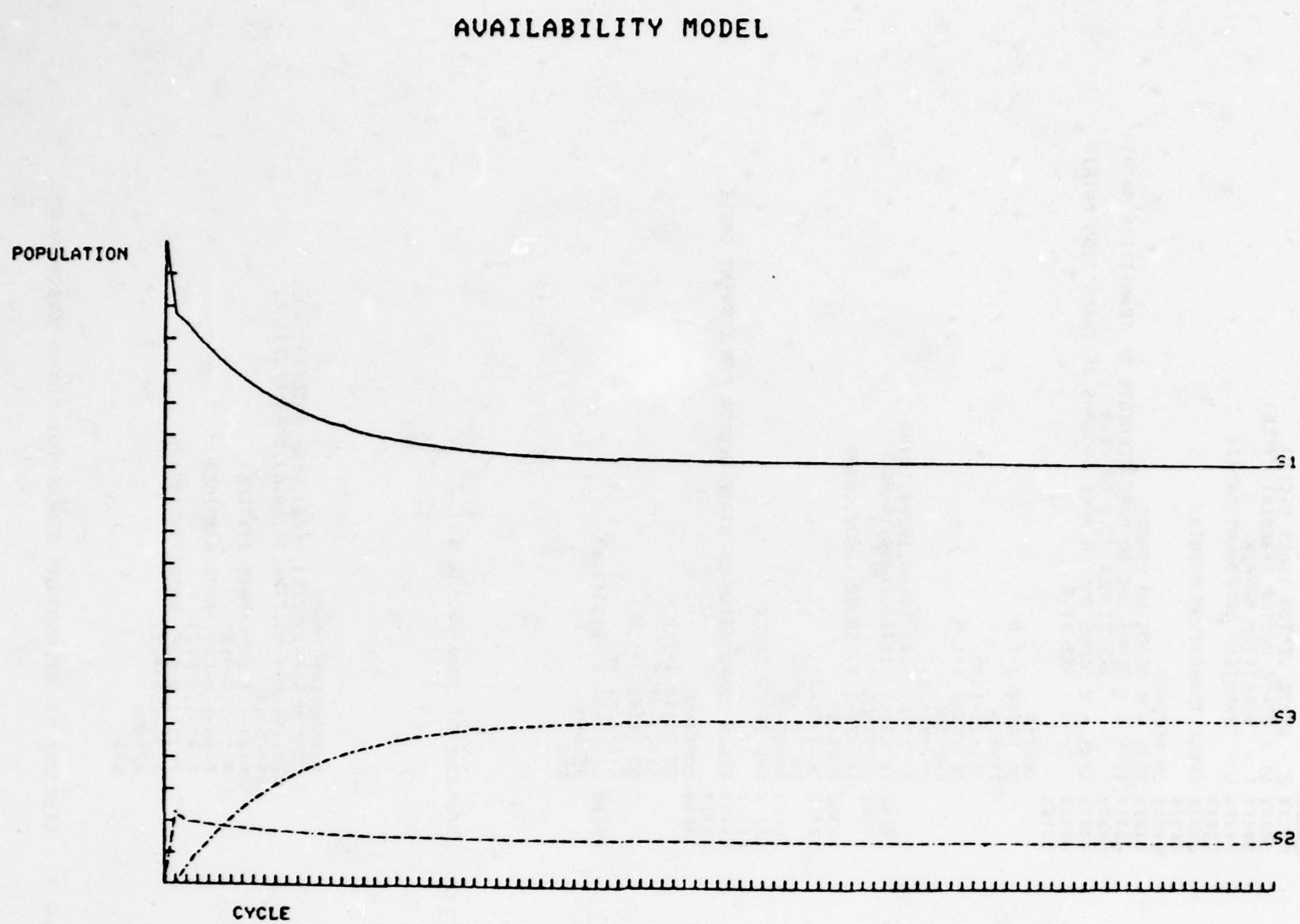

Figure 4. Program output for three stage model

Pr (stay in ready pool)	Pr (mission to ready pool)	Pr (sched maint to ready pool)	Pr (unsched maint to ready pool)
Pr (ready pool mission)	Pr (continue flying)	Pr (sched maint to mission)	Pr (unsched maint to mission)
Pr (ready pool to sched maint)	Pr (mission to sched maint)	Pr (stay in sched maint)	Pr (unsched maint to sched maint)
Pr (ready pool to unsched maint)	Pr (mission to unsched maint)	Pr (sched maint to unsched maint)	Pr (stay in unsched maint)

Figure 5. Transition matrix for four stage model

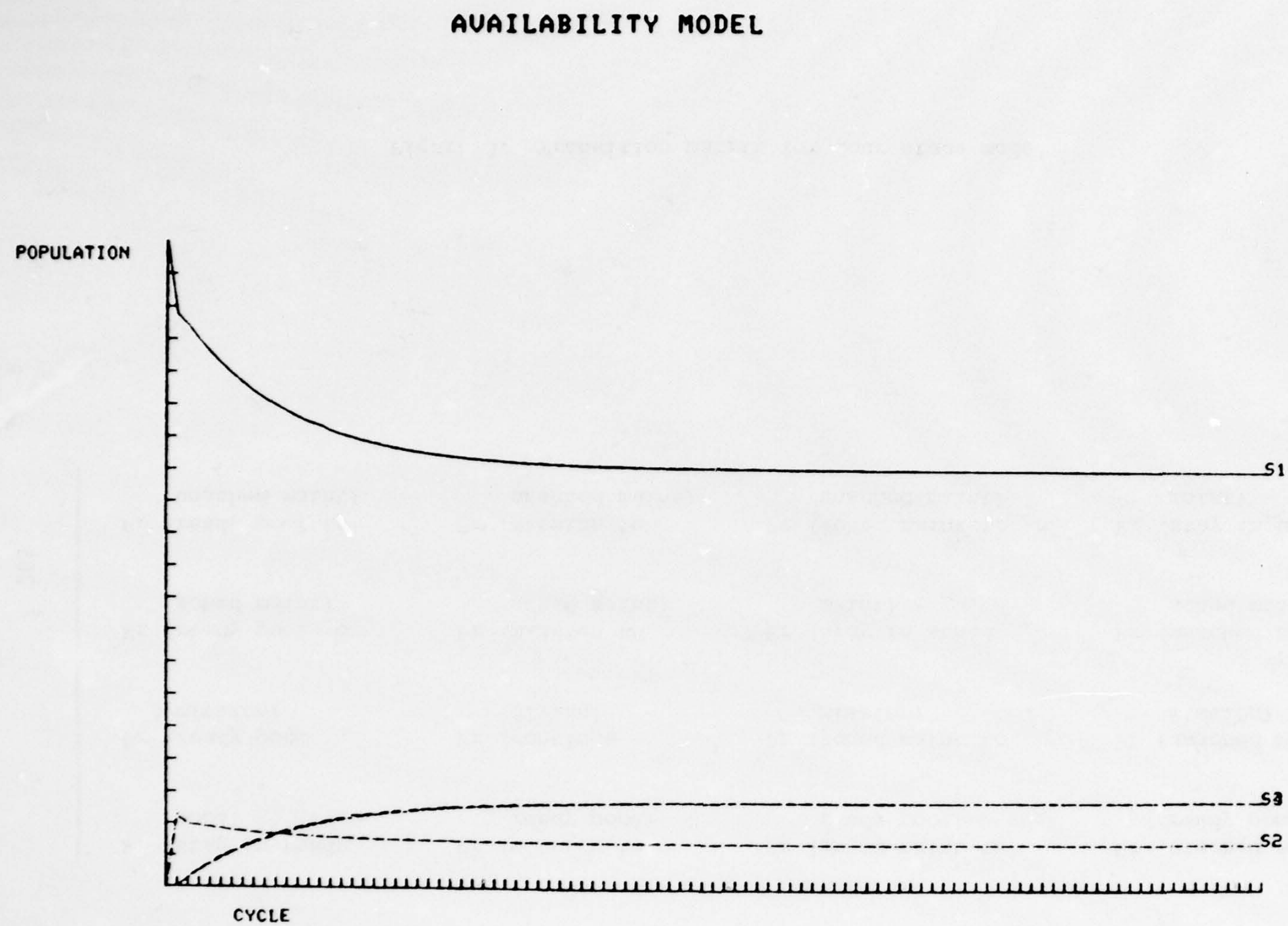

Figure 6. Program output for four stage model

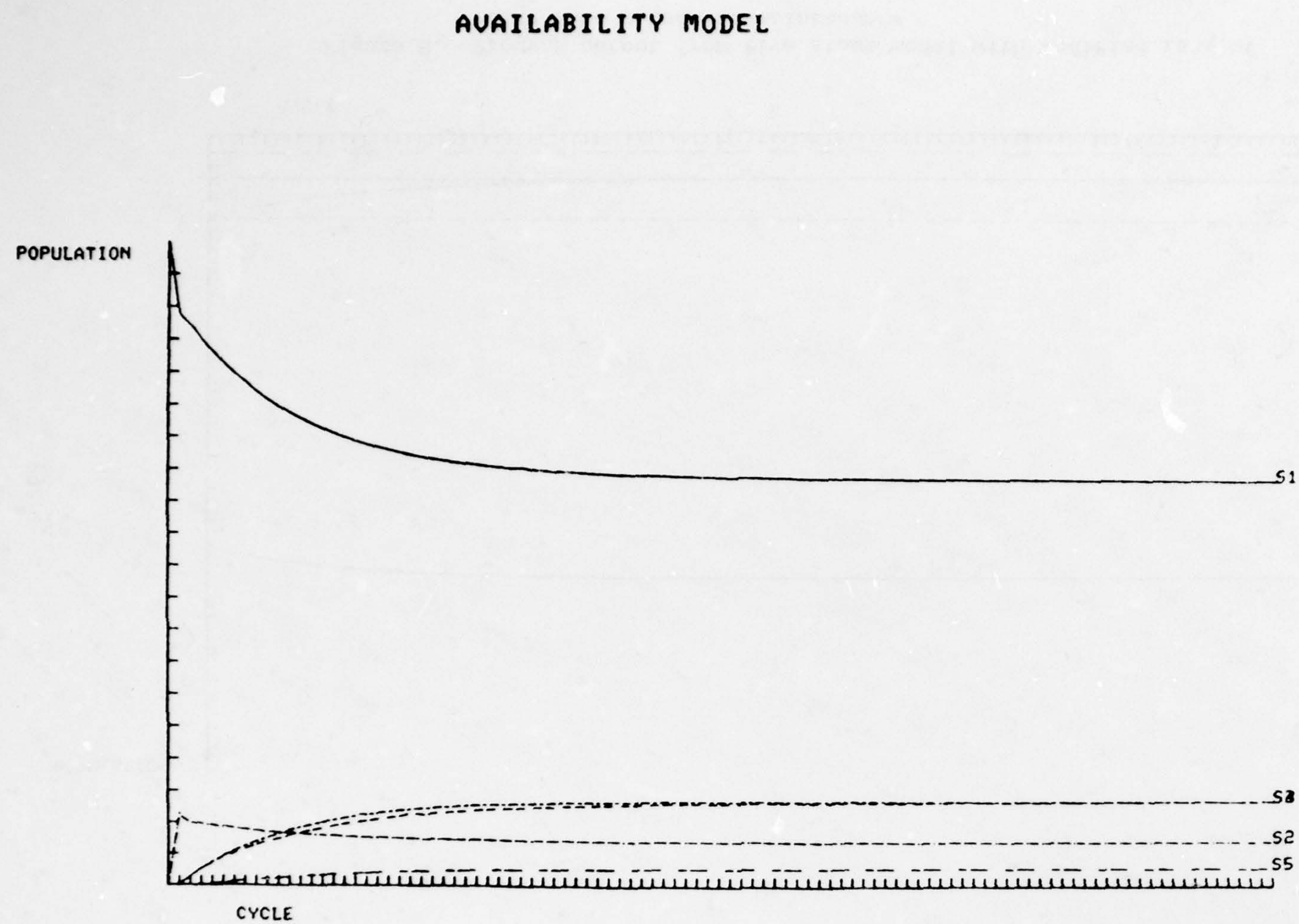

Figure 7. Program output from five stage model

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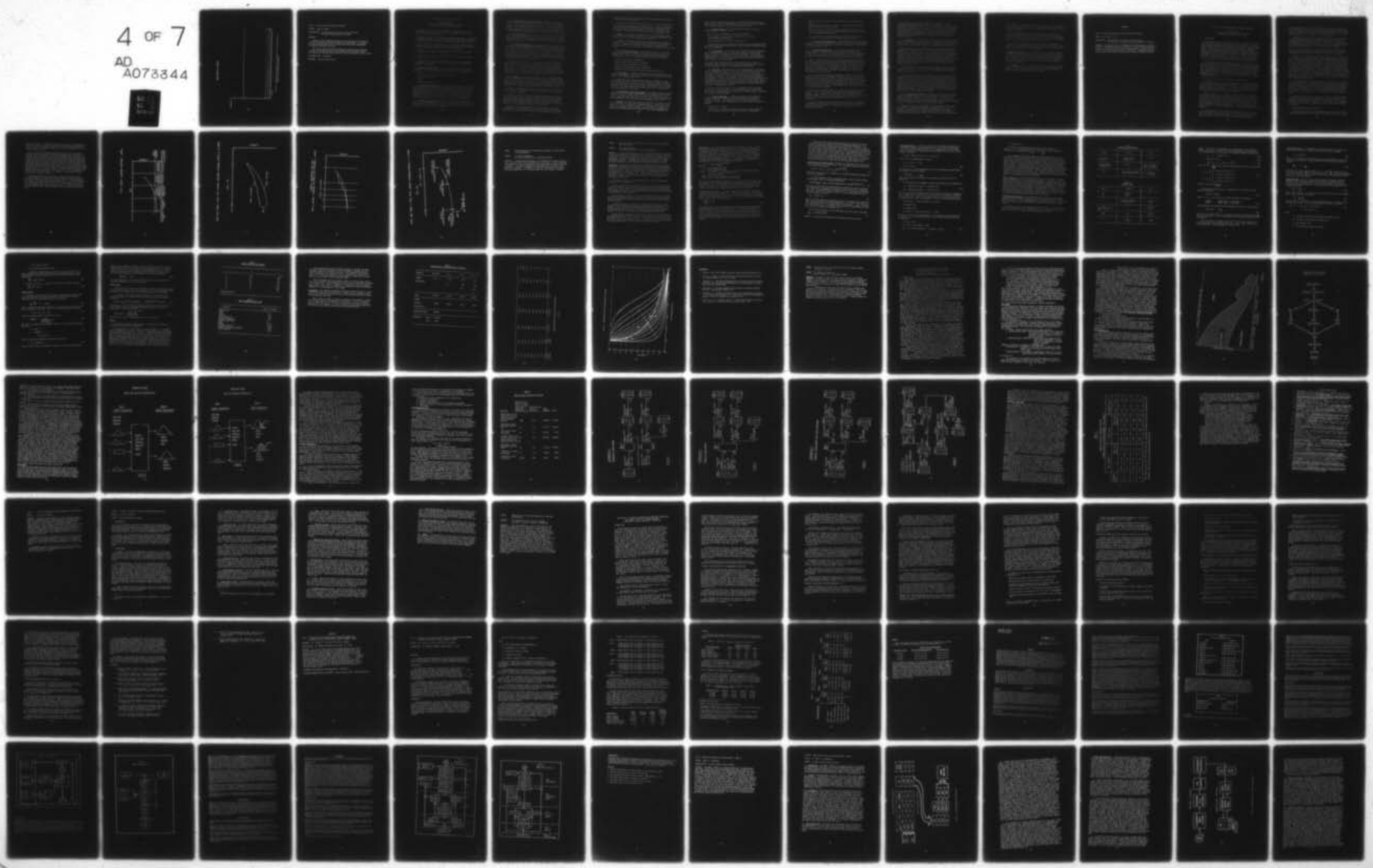

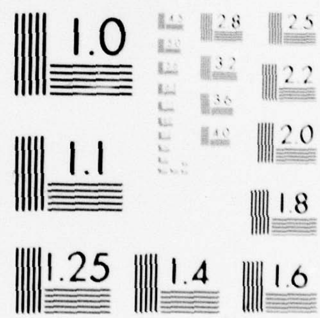

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

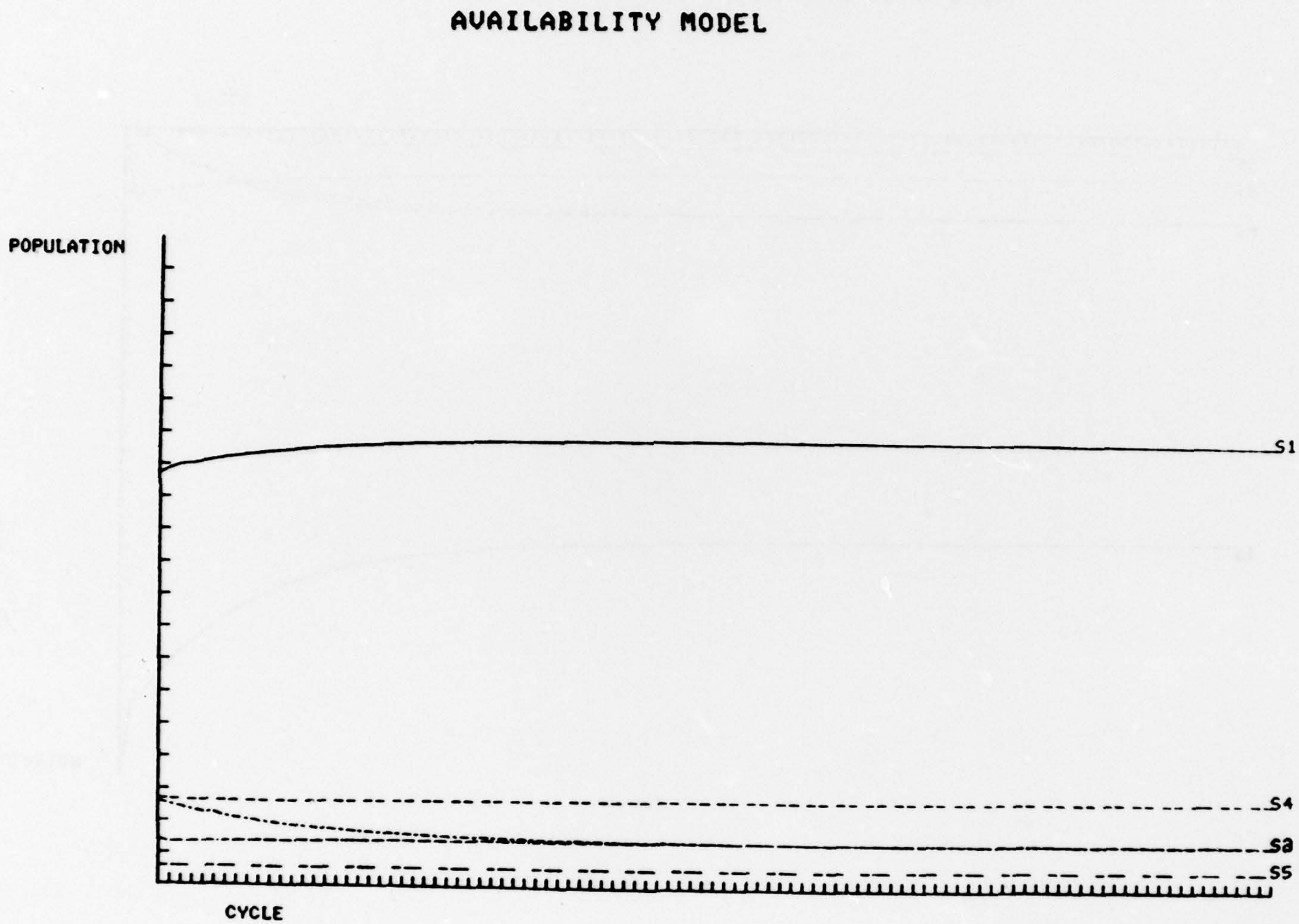

Figure 8. Program output from five stage model with modified rate of entry into scheduled maintenance

TITLE: Contracting for Reliability Growth

AUTHOR: James R. Kniss

ORGANIZATION: U S Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005

ABSTRACT:

Because of the demonstrated need for the government to manage the reliability growth of military systems under development, the growth procedures and concepts must be clearly and effectively implemented in future development contracts.

This paper provides specific guidelines regarding what should be included in the Request for Proposal (RFP), how the proposal should be evaluated by the government and what should be included in the contract.

ESTIMATED TIME: 30 minutes

CATEGORY: Special session topic

CONTRACTING FOR RELIABILITY GROWTH

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1. Growth procedures and concepts must be clearly and effectively translated to any contract for developing a system. This paper will discuss how this should be done.

Because contracts and contracting procedures vary greatly both within and among the services, it will be necessary to reduce these procedures to the basic structure which any contracting procedure must follow.

First prospective contractors must be soliticited, and a detailed accounting of what is needed must be given to each. For most military contracts this is called the Request for Proposal (RFP).

Second, each contractor must respond to the RFP with a statement as to what each believes he can deliver.

Third, after some possible negotiations, a contractor is selected and a contract is signed.

This paper will discuss primarily the Request for Proposal (RFP). The subsequent evaluation of the proposal and contract are primarily a matter of negotiations.

2. Request for Proposal (RFP). The RFP must clearly define what is expected in the contractor's proposal regarding his reliability growth program. It should basically consist of four areas of discussion:

Reliability requirements (interims and final)

Planned growth curves

Testing

Tracking reliability growth

a. Reliability Requirements. Realistic requirements are, of course, basic to the entire reliability program and are not directly associated with the growth program. However, it is important to understand that the growth program is dependent upon realistic requirements since the reliability must, at some time grow to equal or exceed the requirements. Basically the requirements must reflect a need and must reflect the state-of-the-art within constraints on cost. There are two types of requirements that must be considered for reliability growth purposes:

(1) Final Requirements. At some point in time the reliability must equal or exceed some pre-determined goal. The point in time may vary with programs (production, fielding, etc.), but each program is required to specify a final reliability requirement or goal.

(2) Interim Reliability Requirements. These are reliability requirements imposed at specified milestones during the development cycle. The interim requirements must lead to the final requirement and must set a standard on which the progress of the program may be judged. For this reason, interim requirements must be specified for the same hardware and environments as for the final requirement. The interim requirements should be determined by the planned growth curve.

b. Planned Growth Curve. A planned growth curve must be required by the RFP. It should be used to predict the reliability of the item under development at any time during the development process. There are, however, specific requirements regarding this curve that should be specified in the RFP.

(1) Systems, Sub-Systems, and/or Components. The RFP must clearly define what system, subsystem and/or component the planned growth curve is to apply. The most important consideration is that the curve apply to the same system to which the final requirement applies. Normally the requirement, as far as the contract is concerned, applies only to the equipment for which the contractor is responsible, i.e., excludes government furnished equipment (GFE), interface equipment, etc. The planned growth curve, therefore, should also apply only to the equipment for which the contractor is responsible.

There is no need to provide a planned growth curve for subsystems and/or components if there is no contractually binding reliability requirement for that subsystem and/or component. (Such curves may in some cases be of value for analysis or other purposes, but they need not be part of the contract.) This point is mentioned because some contractors have, in the past, included hundreds of meaningless planned growth curves in their reliability program plan, indicating a lack of understanding of the purpose of the growth concept.

(2) Prototypes. If several prototypes are to be developed under different conditions then the RFP must either require a planned growth curve for each condition, must specify an average condition that should lead to the requirement, or must specify which prototype(s) to which the planned growth curve applies. The following are examples of a number of situations that could occur and what should be done in each case.

Example 1. Two prototypes are to be developed. One is to receive fixes as they are developed; the other is to receive few or no fixes until late in the program.

Solution: A growth curve should be submitted for each prototype. The curves should meet at a point later in the program when each prototype has sustained an equal number of fixes. The item receiving the fixes as they are generated should be considered the lead or control prototype and the program evaluation should be based upon it until such time as the other prototype receives the same fixes.

Example 2. Several prototypes are to be developed at different points in time. Newer prototypes will include design changes already incorporated in the older prototypes and will, therefore, be similar in

configuration to the older prototypes at the same time that testing is begun on the newer prototypes.

Solution: It will be assumed that at time, t_i, on the growth curve scale, each prototype will be of approximately the same configuration age although their chronological ages may differ. One planned curve should be submitted which represents an average reliability for the prototypes. The time scale should be in terms of configuration age.

Example 3. One or more prototypes are to be tested under either more severe environmental conditions or less severe environmental conditions than the reliability requirement specifies.

Solution: The planned growth curves normally should not apply to these prototypes. If necessary, however, K-factors can be applied to the data to compensate for unusual environments. Caution must be exercised in the use of K-factors. The K-factor problem will be discussed later.

(3) Historical Information. As mentioned earlier, all available data and/or information should be utilized in the construction of the planned growth curves. The RFP must require that such data and/or information be used. The following information should be required.

Source of data and/or information

Applicability of data and/or information

Degree to which judgement has been used

Method of analyzing data and/or information

Rationale for determining the starting point for the curve

(4) Milestones. All proposed milestones must be identified in the contractor's proposal. These milestones must be associated with specific points on the planned growth curve.

The RFP must specify that milestones should correspond to points where viable decisions can be made. For instance, if numerous fixes are to be incorporated at one time, it would not be appropriate to schedule a milestone at or near this point in time. The reason is that the effectiveness of the fixes cannot be determined until some testing has been conducted subsequent to the fixes.

(5) Relationship to Final Requirement. Obviously the planned growth curve must lead to the final requirement at an acceptable point in time. Normally this point should occur at or before full production of the item. A planned growth curve that does not lead to this requirement may be interpreted as a prediction that the requirement cannot be met.

c. Testing. The RFP must require the contractor to propose a policy for testing the prototypes under development and for reporting the test results. So far as reliability growth is concerned, test results need only to be reported on those systems, subsystems and/or components for which planned growth curves are submitted. Reliability demonstration

tests are not normally required since the techniques outlined in this handbook permit the use of development test data for reliability purposes. The following information should be required in the RFP.

(1) Type of Testing. The contractor must specify the type of testing he plans to conduct, e.g.,

Will fixes be incorporated as they are developed?

Will testing be interrupted for periods of time for the incorporation of many fixes?

Will a combination of the above be employed?

In any event the type of testing will affect the planned growth curve and the RFP must require that the type of testing and the planned growth curve are compatible.

(2) Environments. The RFP must require that proposed environmental test conditions be defined. Only testing conducted in environments defined for the requirements are directly applicable to reliability growth estimation. For instance a field requirement cannot normally be demonstrated in a laboratory environment unless provisions are made for simulating the field environment.

If testing under non-representative environments must be used for reliability growth purposes, then appropriate adjustments must be made. One such adjustment is the use of K-factors discussed next.

(3) K-Factors. When testing is to be conducted under either more severe environmental stress or less severe environmental stress than the field reliability requirement specifies, the use of K-factors may represent an acceptable means of transforming the test results from one environment to another if test results under requirement environments are impossible to obtain. For example, if one hour of environmental stress is considered to be the equivalent of two hours of normal stress, then the K-factor would be two. The times during which the stress was applied could then be multiplied by two and the failures occurring during that time could be appropriately adjusted.

The use of K-factors should not be recommended in the RFP unless there is a valid specific need to use them and unless the contractor can propose a realistic means of arriving at a suitable number. K-factors are, at best, very subjective.

(4) Failure Reporting. The RFP must require the contractor to propose a means for detecting, evaluating and reporting incidents related to failures. He should first specify what information he proposes to record. This information should include the following as a minimum:

Description of incident

Chargeability. Should the incident be charged to the contractor as a reliability failure, and how should this be determined?

Time of failure in terms of the time scale for the planned growth curve.

Classification of failure in terms of its effect upon the mission and/or other criteria such as cost.

The specific form of classification is left to the discretion of the project manager since it is highly dependent upon the particular types of system being developed.

All incidents must be reported and the RFP should clearly prohibit the elimination of any failures on the basis of design fixes.

d. Tracking Reliability Growth. The RFP must require the contractor to propose a means of tracking the reliability growth of the developmental item and of comparing the tracked growth with the predicted growth given by the planned growth curve.

(1) Analytical Methodology. It would not be appropriate for the RFP to require the contractor to commit himself to precisely what methodology will be used. A primary responsibility of this handbook is to convey the message that an acceptable analysis cannot be "cookbook". The data itself must ultimately determine the analytical methodology.

However, both past experiences with military systems under development and a study by Hughes Aircraft have provided convincing evidence that the AMSAA model is the most versatile (robust) procedure for tracking reliability growth. Other models may on particular occasions fit some sets of data better, but the AMSAA model has been found to fit nearly all reliability data. Furthermore, it has been found through experience that in the few cases where the AMSAA model does not fit, other models do not fit either.

For this reason it should be recommended in the RFP that the AMSAA model be applied first to determine its applicability. If a poor fit is obtained, steps should be taken to determine any physical reason for a lack of fit. A common reason, for instance, has been that for periods of time only part of the system is being exercised. During these times, of course, the failure rate would be expected to be lower than during the times that the full system is being exercised. Frequently procedures of this sort are not reported.

There are other common reasons for a poor fit and probably the most common of these is a sudden and unexpected change in the course of a program. Such a change could be the result of a management change, procedural change, failure criteria change, etc. The model can frequently serve as a tool for detecting such changes and/or their effect on reliability.

A poor fit, therefore, is not usually a valid reason for discarding the AMSAA model since frequently such an occurrence reveals information that may have gone unnoticed. Furthermore, the model will usually fit the data in segments.

The purpose of requiring the AMSAA model is not to impose a particular methodology whether or not it is appropriate. If the contractor can show, from the hard data, that the model is inappropriate then other alternatives should be approved. The purpose of requiring the AMSAA model is to impose some "teeth" into the contract which will provide a measure of standardization into military contracts and will prevent the use of complex models that do not reflect the real world and which are usually difficult to understand or refute without an extensive study.

(2) Application. The RFP should clearly indicate to the contractor that the reliability growth curve (tracking curve) will be used to assess the progress of the development effort in comparison to the predicted progress of the development effort as defined by the predictive curve.

This comparison will be made by computing confidence limits for the tracking curve and noting the location of the predictive curve with respect to the confidence limits. If the predictive curve lies below the lower limit of the tracking curve, the reliability growth program is considered ahead of schedule. If the predictive curve lies between the confidence limits, the reliability growth program is considered on schedule. If the predictive curve lies above the upper confidence limit, the reliability growth program is considered behind schedule. The numerical probability associated with the confidence limits should be specified in the contract.

The tracking curve and confidence bounds should be represented by a solid line up to the point in time for which data has been applied. A broken line should be used to project the curve beyond the time for which data is available.

Although primary consideration should be given to the status of the program at the point in time that the latest data was available, it is possible that the program will at that point be on or ahead of schedule but that the projection will not lead to the requirement. This will usually be caused by a planned jump or other rapid increase in reliability at some future time. If such is the case then the projection computed before the jump would not be expected to project to the requirement since the projection is based upon what happened in the past and cannot predict jumps or other rapid increases. This must be understood and discussed in the contractor's proposal.

(3) Planned Course of Action. The RFP must require the contractor to submit a planned course of action based upon the comparison of the predictive growth curve with the tracking curve. If the reliability growth program is either on or ahead of schedule, then no course of action is required. However, if the reliability growth program is behind schedule the contractor must be prepared to take action.

The course of action should include a re-evaluation of the reliability program. He should, for instance, determine whether or not the problem is associated with a particular component or subassembly. If this should be the case, he should conduct an engineering study to determine what can be done to improve the reliability of that component

or subassembly. If nothing can be done he should look at the possibility of improving the reliability of other components or subassemblies in order to compensate for the lower reliability of the component or subassembly in question.

If the system reliability problem cannot be associated with a particular component or subassembly, the contractor should conduct an engineering study of the most prevalent failure modes to determine what can be done to reduce the rate of occurrence of failures to the point where the reliability program will be back on track.

Although the above engineering studies should be conducted in conjunction with government hardware and reliability experts, a detailed report of the findings should be forwarded to the project manager and other appropriate elements of the government.

3. Evaluation of Proposal. The contractor's proposal should address everything requested in the RFP. If he cannot comply with any portion of the RFP he should say why not; if he can comply he should describe how. A series of questions have been suggested to aid the evaluation of the proposal(s). These questions are intended to be included in official DOD documentation, but, for the sake of brevity, cannot be included in this paper.

4. The Contract. After some probable negotiations a contract will be signed. Included in that contract must be a viable reliability growth program to include a planned growth curve(s), acceptable testing procedures, and a proposed method for tracking.

ABSTRACT

TITLE: Reliability Growth Tracking and Control Procedures

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ABSTRACT: This paper discusses management and methodological concepts for effective tracking and control of reliability growth during development testing. In particular, the concepts and usefulness of Idealized, Predictive and Tracking growth curves are addressed. Management guidelines are also given for setting milestones and tracking reliability growth.

RELIABILITY GROWTH TRACKING AND CONTROL PROCEDURES

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1. INTRODUCTION

The reliability goal for a military system is rarely met with the first design and, hence, the system is usually subjected to a development testing program where the reliability is improved through testing, identification of problem areas and the incorporation of appropriate fixes. Unless the reliability growth for the system is properly managed, the program manager may not realize that serious reliability problems exist until the system is subjected to a demonstration test. Invariably, when major reliability problems are surfaced late in the development program, the result is either a costly delay in the deployment of the system while engineering modifications are made, or the system is deployed with lower reliability than originally required.

In this paper we discuss management concepts for planning and tracking system reliability growth. Specifically the roles of Idealized and Predictive growth curves for planning the reliability and establishing various milestones are discussed. Also, the use of the Tracking growth curve for evaluating the reliability status of the program is discussed. These management concepts are designed to improve the chances of surfacing major problem areas earlier in the development program so the program manager may take appropriate corrective measures in a timely and cost-effective manner.

2. THE IDEALIZED AND PREDICTIVE RELIABILITY GROWTH CURVES

In a general sense, the development program can usually be divided into several major phases as shown in Figure 1. The reliability growth for the system is often depicted as a smooth curve over these various phases, as shown also in Figure 1. This smooth representation of reliability growth is generally idealistic, and does not convey the way reliability will actually grow during development.

A major test cycle is a distinct test phase of the development program usually resulting in a significant jump in the system reliability. If we divide the development testing program into its major test cycles and join, by a smooth curve, the predicted reliability values for the system at the end of these test cycles, then the resulting curve represents the general overall planned pattern for reliability growth. This is the idealized reliability growth curve. It does not represent the actual pattern for reliability growth within each of the major test cycles, however.

To see how reliability may actually grow during a major test cycle, we note that there are two basic types of development testing, namely, "test-fix-retest" and simply "test-fix." During a test-fix-retest program, the system is tested and problem failure modes determined.

Fixes for these deficiencies are incorporated into the system which is then retested to verify the fixes and surface new problem areas. During a test-fix program, significant fixes are not introduced into the system during the test cycle but rather are incorporated at the end of the test, resulting usually in a large jump in system reliability.

The reliability growth during a major test cycle is often a combination of these two basic types of testing. Typically some fixes are introduced into the system during test, and other fixes are delayed, and incorporated at the end of the test. The result is a smooth increase in reliability until the end of the test cycle, then a jump may occur because of the delayed fixes. This is illustrated in Figure 2.

We note that during a test-fix program, the impact of the delayed fixes on the system reliability cannot be measured from actual system performance until the data from the next test phase are collected.

The predictive reliability growth curve shown in Figure 3 depicts the way reliability is actually planned to grow during each of the major test cycles. The corresponding idealized curve, illustrating the overall pattern for reliability growth is also shown. The predictive curve shows the type of reliability testing planned for each of the major test cycles. It also gives the expected reliability at the beginning and end of the test cycles. In particular, the amount of reliability improvement that is planned during the test cycles by incorporating fixes during the test is reflected by the smooth curve. Also, the amount of reliability improvement planned as a result of incorporating delayed fixes at the end of the test cycles are also shown. The predictive reliability growth curve, constructed in this fashion, gives the program manager various milestones at the beginning and end of each major test cycle to be used for controlling the reliability growth process.

At the beginning of the development program and before hard reliability data are generated, the program manager should construct a predicted reliability growth curve. This is an initial planning curve, based on the best available information from the contractor and program manager's office, on how reliability is expected to grow during each of the major test cycles. Its purpose is to give a realistic indication of what the reliability is expected to be at various points in the development cycle.

The idealized reliability growth curve is used for overall planning. The predictive curve is used for determining specific milestones and objectives at each stage in the program. The specific milestones and objectives are needed when tracking the system reliability to determine if the reliability effort is acceptable, and to surface major problem areas early.

3. THE TRACKING RELIABILITY GROWTH CURVE

At major decision points in the program a numerical measure of the system reliability should be determined and compared against the planned

goal at that time. It should be noted that for effective management and reduced risk, the milestones should be set so that viable alternatives exist, in terms of available resources to recover the program, if a reliability goal is not met.

As a tool for surfacing major problem areas as early as possible, a tracking reliability growth curve is often employed once sufficient reliability data are generated. Using data throughout the test cycle, the tracking curve provides an estimate of the current status of the system reliability and generally makes a projection of the expected reliability at the end of the test cycle. These projections are usually made on the assumption that the reliability effort in the future will continue in the same fashion demonstrated up to the present time. Since the estimate and projections are based on fixes that are being incorporated into the system during the test (i.e. the test-fix-retest portion), the projections do not estimate the jump in reliability at the end of the test cycle due to the incorporation of delayed fixes. An example of a tracking reliability growth curve is shown in Figure 4.

The program manager can continually evaluate the status of the reliability program by comparing the current estimates and projections to the goals and milestones from the predictive curve. If the projections, for example, are significantly below the milestones at the end of the test cycle, then corrective action can be taken. This reduces the risk of not attaining the final reliability goal and is, of course, more timely and cost effective than taking corrective action at the end of the test cycle.

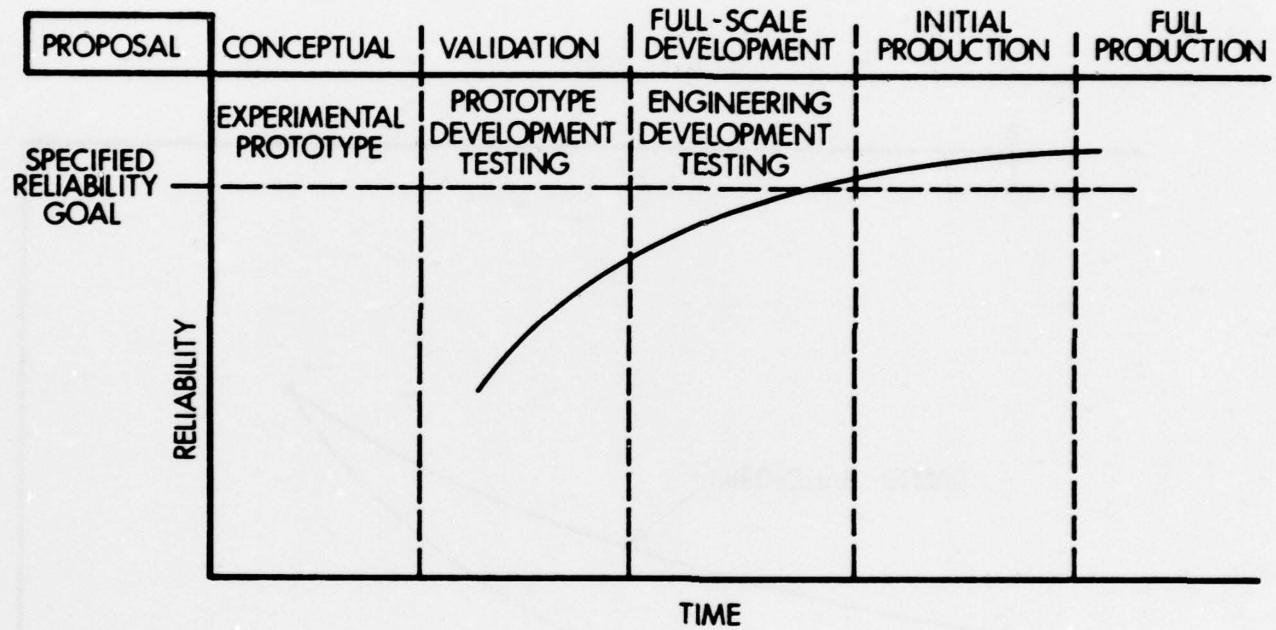

Figure 1. Idealized Reliability Growth Curve.

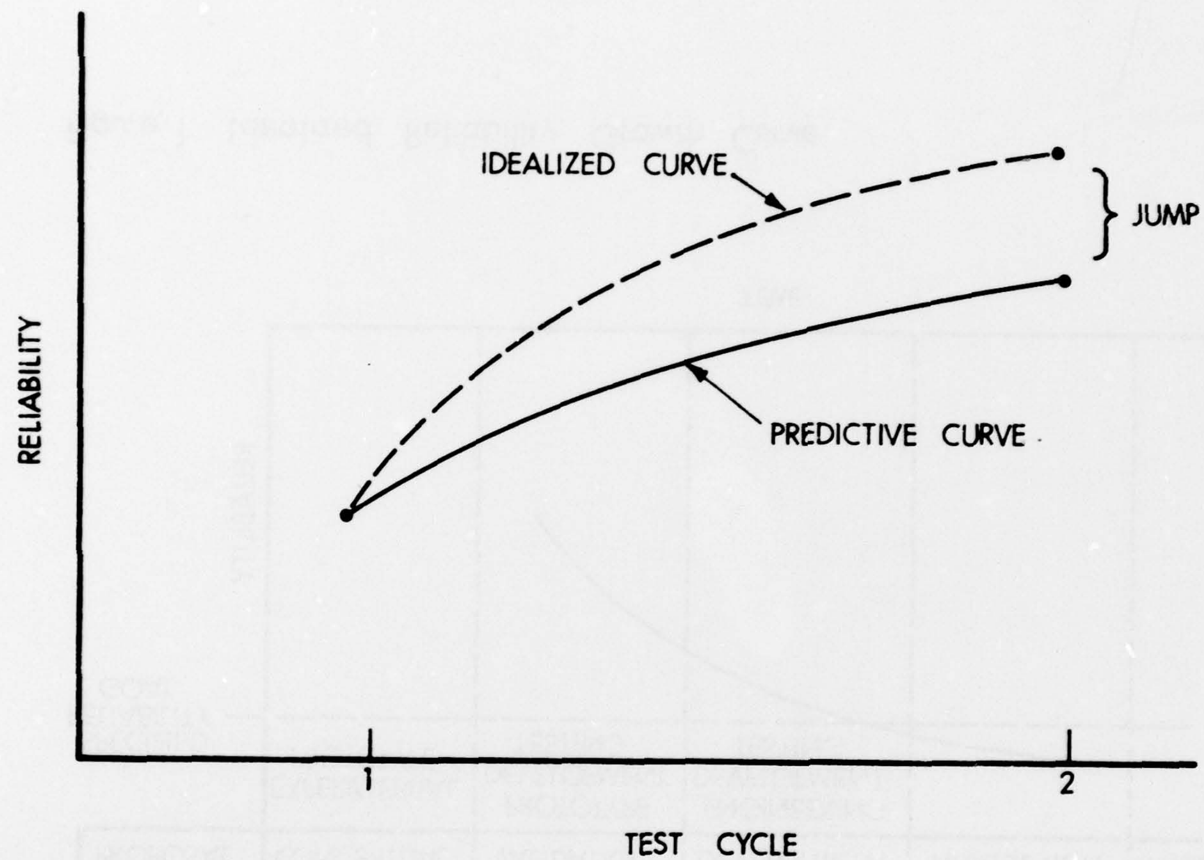

Figure 2. A Typical Predictive Reliability Growth Curve Over a Major Test Cycle

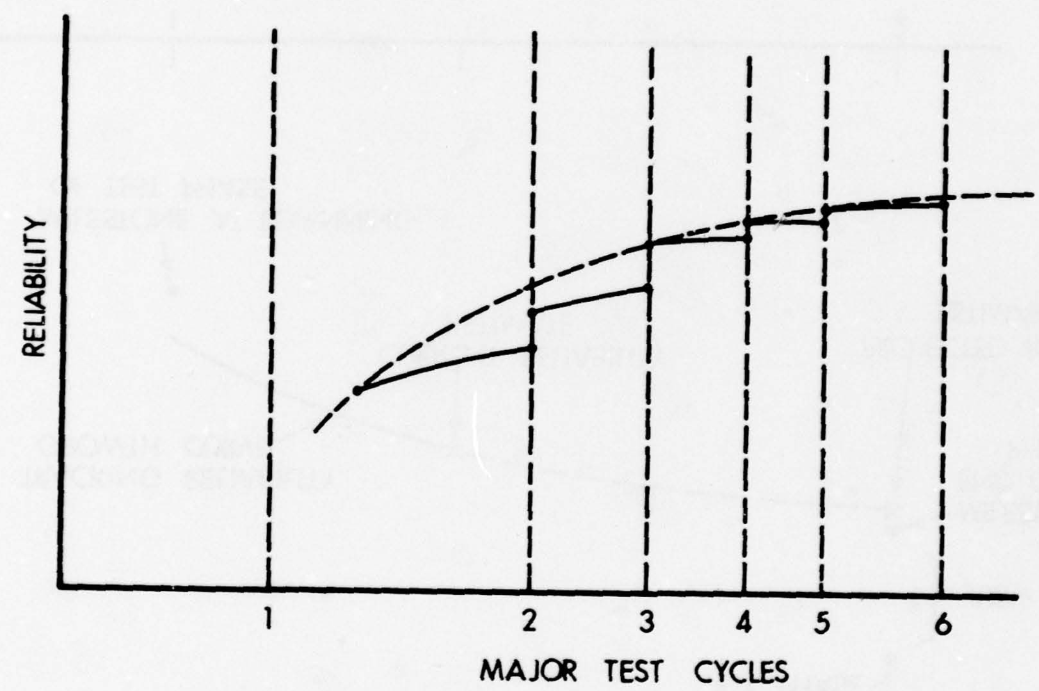

Figure 3. Idealized and Predictive Reliability Growth Curves Over the Development Program.

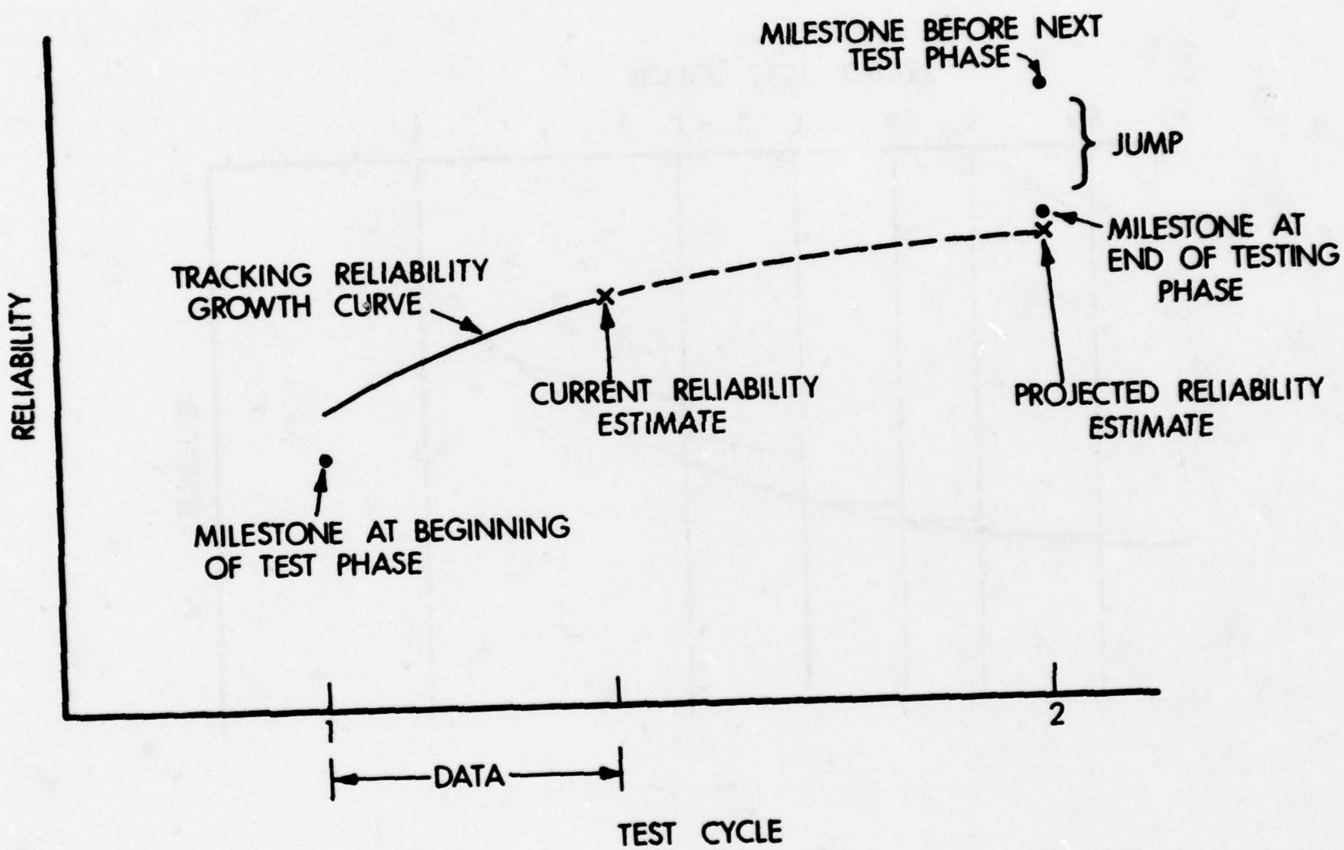

Figure 4. A Tracking Reliability Growth Curve Over a Major Test Cycle.

TITLE: Modeling Reliability Conditioned on Usage in an Operational Test Environment

AUTHOR: Mr. Leslie Lancaster
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ABSTRACT: A computerized methodology for analyzing the failure data process is developed for an operational test environment. System reliability is modeled by a Weibull distribution with usage dependent shape and scale parameters. The model parameters are estimated by an iterative ridge regression technique. An example is given to illustrate how the shape and scale parameters and the failure rate vary with respect to usage.

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Background. Historically, the Weibull distribution has been used extensively for reliability investigations of failure data in a developmental testing (DT) environment. In this environment performance is characterized by first failures. Current procedures in an operational testing (OT) environment are to utilize DT tools. That is, operationally, every time the weapon system is repaired, it is assumed to be as good as new, an assumption failure. Therefore, new tools need to be developed for the operational environment.

This report discusses a new methodology to be used for repairable systems in an OT environment.

Further, one weapon may fail n times in m ways, but the current state of the art analysis is based upon total number of failures without distribution over failure types. The developed methodology can uniquely handle this problem by batching into one distribution and assigning to each failure type a different usage criterion.

The analytical problem is to derive the conditional survivor function given that the weapon has aged by repeated use and certain weapon components are continuously being replaced either by failure or through preventive maintenance.

A renewal process is a series of events where units (miles, rounds, minutes) between events are independent and identically distributed. For example, the age replacement criterion generates two renewal processes; one corresponds to the sequence of failures; the other corresponds to the sequence of removals of both failed and deliberately replaced items.

The developed capability may be useful to predict the field/operational reliability and necessary maintenance support requirements based upon an abbreviated history of a weapon system. For example, given a weapon system in combat, what is the probability that the weapon will operate successfully for K more units given that its usage has already been t units.

Introduction. In an operational test (OT) environment a system is tested whereby the units (time, rounds, miles, etc.) at failure are recorded as a dependent sequence of intervals. The system is repetitiously repaired and continuously tested in as realistic an operational environment as possible as dictated by a designed testing procedure. Thus, the sequence of failure intervals form a renewal process or time series such that the intervals form a dependence structure. To reflect age or usage in the OT environment the observed time series is modeled by a conditional time dependent Weibull distribution expressed as follows:

$$R(x/t) = \exp\left\{-\left(\frac{x-\gamma}{\theta(t)}\right)^{1/\lambda(t)}\right\} \tag{1}$$

where

X = units between failure
t = age or usage in units
R(x/t) = reliability of operating x units without failure given that the age or usage is already t units
γ = location parameter
$\theta(t)$ = age or usage dependent scale parameter
$\lambda(t)$ = age or usage dependent shape parameter

That is, the scale and shape parameters vary accordingly with age or usage. For example, after estimating the Weibull parameters from OT results, the system user can plot a reliability curve for each fixed value of age or usage. Output from the computerized methodology includes various values of $\theta(t)$ and $\lambda(t)$ as t is incremented over the life of the test.

Computerized Methodology. A computer package is developed to describe the model expressed by the equation (1). Input to the package is the failure data in the observed order which can be considered as intervals in the time domain. These intervals represented by t and x are the actual observations. For the special case given as follows:

$$\theta(t) = \theta$$
$$\lambda(t) = \lambda \tag{2}$$

the actual order of the observations are insignificant and represents the usual developmental testing (DT) situation. An initial pass of the data for this special case given by equation (2) is made for two reasons. First, this case is the three parameter Weibull case (references 5 and 6) and the resulting output is used for comparitive purposes. Second, the estimated location parameter is assumed to be a good estimate and is therefore used at this estimated value for estimating the age or usage parameters.

Output from the computerized methodology is a powerful means for presenting analytical results to the OT independent evaluation. For example, besides expressing varying values of $\theta(t)$ and $\lambda(t)$, other key parameters are also expressed. For example, for t fixed the Weibull mean and standard deviation, the failure rate at the median, and R(mean/t) are also tabled. These tabled values form a comprehensive picture of the resultant system based on the failure data. Plots of the family of reliability curves provide a descriptive picture of the system statistics. Of further interest is finding the age or usage when $\lambda(t) = 1$, the negative exponential distribution trade-off point. These output results provide useful means for comparing various candidate systems, etc.

Estimation of the Coefficients. Equation (1) expresses the general model used to represent the failure data. For estimation purposes, equation (1) is re-written as follows:

$$R(x/t) = \exp\left\{ -b_1 t^{b2} (x-\gamma)^{b_3 + b_4 \ln t} \right\} \tag{3}$$

where the coefficients are estimated by a graphical plotting technique via classical regression.

To write equation (3) as a regression model, take the natural logarithms twice to get the following expression:

$$\ln \ln R^{-1}(x/t) = \ln b_1 + b_2 \ln t + b_3 \ln(x-\gamma) + b_4 \ln t \ln(x-\gamma) \tag{4}$$

Note that in log-space the observables plus their first order interaction are represented as independent variables in the regression. On representing x and t as observables from a sample size of n and, therefore introducing error, equation (4) takes the form of a linear regression written in matrix notation as follows:

$$\underline{Y} = X\underline{\beta} + \underline{\epsilon} \tag{5}$$

Hence, classical regression techniques are used to estimate the coefficients and, thus, to estimate the Weibull parameters. Also, hypothesis tests can also be made directly on the coefficients in the classical sense. Although not treated here, serial correlation was significent in applications in the error vector as expressed by equation (5).

The classical estimate of the coefficient vector is given as follows:

$$\underline{\hat{\beta}} = (X'X)^{-1} X'\underline{Y} \tag{6}$$

However, on using penalty functions, this estimate will be modified.

<u>Plotting Positions</u>. In order to convert the conditional reliability to a dependent variable in the regression model, plotting positions based upon the observables shall be used. For a sample size of n, the model given in equation (3) expressing the kth observation or failure is represented as follows:

$$R(x/t) = R(x_K / t_o + x_1 + \cdots + x_{K-1}) \tag{7}$$

That is, for an initial age or usage t_o

$$\begin{aligned} t_k &= t_o + x_1 + \ldots + x_k \\ x_k &= t_k - t_{k-1} \end{aligned} \tag{8}$$

for K=1,2...,n. The plotting points for the corresponding reliabilities are assigned values as follows:

$$R(x_K / t_{K-1}) = \frac{K}{n+1} \tag{9}$$

where the ordering relationship for assigning the points needs to be determined.

To determine this assignment, consider the following two assumptions:

$$\begin{aligned} &\text{(a)} \quad R(x+y/t) < R(x/t) \\ &\text{(b)} \quad R(x/t+\Delta) < R(x/t) \end{aligned} \tag{10}$$

Due to the monotonicity properties of the reliability function, assumption (a) is always true. However, over the interval of observables, assumption (b) could be true or false with respect to some cross-over-value x* (see equations 16-18). That is, assumption (b) has the following possibilities:

(a) True for $x > x^*$ and false for $x < x^*$

(b) Always True

(c) Always False

(d) False for $x > x^*$ and True for $x < x^*$

Therefore, the a priori determination of the plotting positions expressed by equation (9) is a difficult problem. The following possibilities can be mentioned:

(a) Order on x_k

(b) Order on the product $x_K t_K$

(c) Order on the expression $c_1 x_K t_K + c_2 x_K$ (11)

(d) Order on t_k

(e) Add the point values from (a) and (b) and normalize where $c_1 + c_2 = 1$ and where the order relationship is from maximum to minimum for the assignment from $\frac{1}{n+1}$ to $\frac{n}{n+1}$.

All possibilities given by equation (11) could be tried and the one giving the smallest standard error of the estimate (SEOE) in the regression could be selected. However, most of the time in applications of the methodology, ordering on X_k gave the smallest SEOE, so it should always be tried. Further, the user may want to select a possibility not having the smallest SEOE. For example, the user may prefer possibility (d) rather than (a) due to a heavy burden on unit usage. Also, some cases may dictate the selection of another possibility having a higher SEOE which will become obvious on inspection of the output. Thus, the user becomes part of the iterative loop and experience is an asset. From applications of the methodology, it was found that the selection procedure for the dependent variable vector in the regression was very sensitive.

Rank Correlation. Define the ordering of the x's from minimum to maximum as the standard order. Since the random variable x is assumed to follow a Weibull distribution, the regression coefficients for this ordering or plotting position possibility can always be estimated. However, key parameters and the residual analysis are used to check the goodness-of-fit. Rank correlation is used to determine whether the regression coefficients for the other possibilities can be estimated. Beginning with the standard order, the other possibilities are ordered and their rank correlations are computed. If any rank correlation is less than a value determined by the user, say 0.1, then that plotting position possibility is skipped.

Parametric Relationships. On equating equations (1) and (3) convenient relationships are derived between any pair of the three parameters $\lambda(t)$, $\ln \theta(T)$, and $\ln t$. These relationships are displayed in Table 1. Therefore, once the coefficients are estimated, the families of curves can be easily computed.

Note that all six of the expressions given in Table 1 are linear fractional transformations (see reference 1) with zero imaginary parts. Hence, the limiting cases are easily found and displayed in Table 2.

TABLE 1
PARAMETRIC RELATIONSHIPS

$\lambda(t)$	$\ln \theta(t)$	$\ln t$
$\frac{1}{b_3+b_4 \ln t}$	$\frac{-b_2 \ln t - \ln b_1}{b_3+b_4 \ln t}$	$\ln t$
$\frac{b_2+b_4 \ln\theta(t)}{b_2 b_3-b_4 \ln b_1}$	$\ln \theta(t)$	$\frac{\ln b_1 + b_3 \ln\theta(t)}{-b_2 - b_4 \ln \theta(t)}$
$\lambda(t)$	$\frac{-b_2+\lambda(t)(b_2 b_3-b_4 \ln b_1)}{b_4}$	$\frac{1 - b_3 \lambda(t)}{b_4 \lambda(t)}$

TABLE 2
LIMITING CASES

$\lambda(t)$	$\ln \theta(t)$	$\ln t$
$\frac{1}{b_3}$	$\frac{-\ln b_1}{b_3}$	0
1	$\frac{-b_2+b_2 b_3 - b_4 \ln b_1}{b_4}$	$\frac{1-b_3}{b_4}$
$\frac{b_2}{b_2 b_3 - b_4 \ln b_1}$	0	$\frac{- \ln b_1}{b_2}$
∞	∞	$\frac{-b_3}{b_4}$
0	$\frac{-b_2}{b_4}$	∞

Bounds. The model is characterized by various bounds on the parameters. From the properties of linear fractional transformations and since the shape parameter has to be positive, the following inequalities must hold:

$$b_3 > 0 \quad (\text{when } t = 1) \tag{12}$$

$$b_2 b_3 \neq b_4 \ln b_1 \tag{13}$$

$$b_2(1 + b_3) > b_4 (\ln b_1 - \ln\theta(t)) \tag{14}$$

Also, let $\delta = \frac{|b_3|}{|b_4|}$, then upper or lower bounds are given on t as follows:

$$\ln t < \begin{cases} -\delta, & \text{for } b_3 < 0 \text{ and } b_4 < 0 \\ \delta, & \text{for } b_3 > 0 \text{ and } b_4 < 0 \end{cases} \tag{15}$$

$$\ln t > \begin{cases} -\delta, & \text{for } b_3 > 0 \text{ and } b_4 > 0 \\ \delta, & \text{for } b_3 < 0 \text{ and } b_4 > 0 \end{cases}$$

Equality holds when $\frac{\partial R(x/t)}{\partial t} = 0.$

Further bounds which relate to assumption (b) of equation (10) are given by looking at:

$$R(x^*/t) = R(x^*/s) \tag{16}$$

where $t \neq s$. For this case the following expression is obtained:

$$\frac{\lambda(s)}{\lambda(t)} = \frac{\ln(x^* - \gamma) - \ln\theta(s)}{\ln(x^* - \gamma) - \ln\theta(t)} \tag{17}$$

On substituting the coefficients this expression reduces to the following:

$$\ln(x^* - \gamma) = -b_2/b_4 \tag{18}$$

Note that for $\theta(t)=x^*-\gamma$ this is the same situation as $\lambda(t)\to 0$ and $\ln t \to \infty$. The cross-over-value, x^*, is a key parameter for preventive maintenance considerations.

Also, from Table 1, column 1, note that $\lambda(t)$ is never constant as t varies since $\lambda(t) = \lambda(s)$ implies that $s = t$. Hence, $\lambda(t) = \lambda(s)$ refers to the degenerate case as expressed by equation (2).

Correlation Matrix. On estimating the coefficient vector in equation (5), let C denote the matrix of simple correlations defined as follows:

$$C = D^{-1}X'XD^{-1} \tag{19}$$

where D is a diagonal matrix whose elements are determined such that C has all ones on its diagonal. Define pseudo multiple correlations squared as follows:

$$\delta_K^2 = 1- \frac{1}{\mu_k} \tag{20}$$

where μ_k is the kth diagonal element of C^{-1}. Each δ_k corresponds to one of the four variables making up the design matrix. Both types of correlations are used for constructing the decision criteria for utilizing penalty functions in an iterative fashion.

Ridge Regression. Due to a set of possibly highly correlated variables, Marquards ridge regression technique is utilized in estimating the coefficient vector in equation (5). An iterative procedure is performed in the estimation process whereby the starting value for the penalty function is given as follows:

$$\lambda_o = \frac{r}{\kappa_o} - 1 \tag{21}$$

where κ_o (for example, $\kappa_o = 0.999$) is chosen by the user and r is determined by the sample and given as follows:

$$r = \max_{j,k} \rho_{jk} \tag{22}$$

where the ρ_{jk} are elements of the correlation matrix C. At each step of the iterative process, a new correlation matrix is derived as follows:

$$\left\{ C + (\lambda_o + q\epsilon)\, I \right\} \longrightarrow C_q^* \tag{23}$$

For $q=0,1,2,.....$

where

C = original correlation matrix defined by equation (17)

λ_o = starting value defined by equation (21)

q = the integral step

ϵ = the step size as given by the user

I = the identity matrix

Cq* = the qth correlation matrix

Adaptive stopping rules are set up in the next section and if these stopping rules are satisfied, then the iterative process is terminated on the qth step with an estimate of the coefficient vector given as follows:

$$\hat{\beta}_q = (DC_q^* D)^{-1} X' Y \tag{24}$$

Note that as $q \to \infty$, $C_q^* \to I$ and for this limiting situation:

$$\hat{\beta}_q \to D^{-2} X' Y \tag{25}$$

STOPPING RULES

To execute termination of the iterative estimation process stopping rules are utilized. The iterative process in the estimate of β_q is continued until the following inequality is satisfied:

$$\max_{K} \delta_K^2 < 0.9999 \tag{26}$$

Also, a condition number (see reference 3) is imposed on the matrix inversion as expressed as follows. Write the correlation matrix as follows:

$$C = (\underline{C}_1, \underline{C}_2, \underline{C}_3, \underline{C}_4) \tag{27}$$

then the condition number is defined as follows:

$$\text{norm}|C| = \frac{|C|}{\prod_{j=1}^{4} \sqrt{\underline{C}_j' \underline{C}_j}} \tag{28}$$

Now since C is assumed to be positive definite, the following inequalities must hold:

$$0 < |C| < 1$$

$$1 < \sqrt{\underline{C}_K' \underline{C}_K} < 2 \tag{29}$$

for K=1,2,3,4

Hence, the condition number is constrained as follows:

$$0 < \text{norm}|C| < 1 \tag{30}$$

where the upper limit is achieved for completely uncorrelated parameters.

However, when norm$|C|$ = 0 (10^{-k}), a change in the kth or earlier significant digit of any of the elements of the correlation matrix C can lead to changes of order 10^k in the estimate of the coefficient vector. Therefore, the iterative process in the estimation of β_g is continued until the following inequality, as determined by the user, is satisfied:

$$\text{norm}|C| > 5{*}E\text{-}6 \tag{31}$$

Also the inequalities on the coefficients must also be satisfied before executing termination of the iterative loop.

FAILURE RATE

The failure rate defined as the number of failures per normalized unit (miles, rounds, minutes, etc.) can be used to aid in the interpretation and to help the user choose the correct plotting position for his sample.

In terms of conditional distribution functions, the failure rate function, $r(x/t)$, is related to the reliability function for fixed t as follows:

$$R/x/t) = \exp\left\{-\int_0^x r(y/t)\,dy\right\} = f(x/t)/r(x/t) \tag{32}$$

where f(x/t) is the conditional probability density function. Now fix x at the median, then the corresponding failure rate for the Weibull distribution is given as follows:

$$r(\text{median}/t) = \frac{(\ln 2)^{1-\lambda(t)}}{\lambda(t)\ \theta(t)} \tag{33}$$

The idea is to see how r(median/t) behaves as t increases.

EXAMPLE:

To preclude an indepth investigation, an example will be given to illustrate the computerized methodology.

The observations for this example are given in Table 3. Chronologically it appears that, since the failures are happening faster, the failure rate should be increasing over t. However, from the list of key parameter values for the three parameter Weibull case as given in Table 4, since the shape parameter is greater than one, the failure rate is decreasing over x. Hence, DT information cannot be used to answer OT problems, since no DT information is given on the behavior of failure rate over t, and since the decreasing failure rate over x is misleading. Equality between DT and OT holds if the n observations are first failures from n different systems. Then $t_i = t_o$ for all i which is the degenerate case given by equation (2).

TABLE 3
OBSERVATIONS FOR THE EXAMPLE

I	x	t
1	30	1.0*
2	15	30
3	10	45
4	15	55
5	10	70
6	5	80
7	5	85
8	4	90
9	4	94

*Changed from 0.0

TABLE 4
THREE PARAMETER WEIBULL CASE

Parameter	Value or Estimate
Sample size	9
Scale	7.13
Shape	1.52
Location	3.74
Rank correlation	-.88
Minimum observation	4
Maximum observation	30
Mean	13.35
Median	7.83
Standard deviation	15.09
Standard deviation (residual)	1.68
Mean (residual)	0.13

For the regression model as developed, Table 5 displays the simple and pseudo multiple correlations of the independent variables and the condition number of the matrix inversion. The regression coefficients and the goodness-of-fit parameters for the residuals are also given in Table 5. The plotting position for this example is based upon the ordering of the X_k's since it had the smallest SEOE.

Table 6 displays some key parameter values for various usage values. Note that the failure rate decreases initially and then increases as implied by the observables. Graph 1 displays the reliability curves for various usage values. Note that the reliability is degraded as usage increases as implied by the observables for this example.

Conclusions. The example illustrates differences between OT and DT. Table 4 displays output from the DT approach. Tables 5 and 6 and Graph 1 show some of the information gained by using the developed methodology as needed for answering OT questions.

Plots similar to Graph 1 could be very useful for comparing or combining different samples when answering OT objectives. Also, the user may want to experiment with variations on the definition of usage as given by equation (8). For example, t_k could be defined as miles plus rounds prior to the kth failure while x_k is strictly miles between failure.

TABLE 5

CORRELATIONS OF THE INDEPENDENT VARIABLES

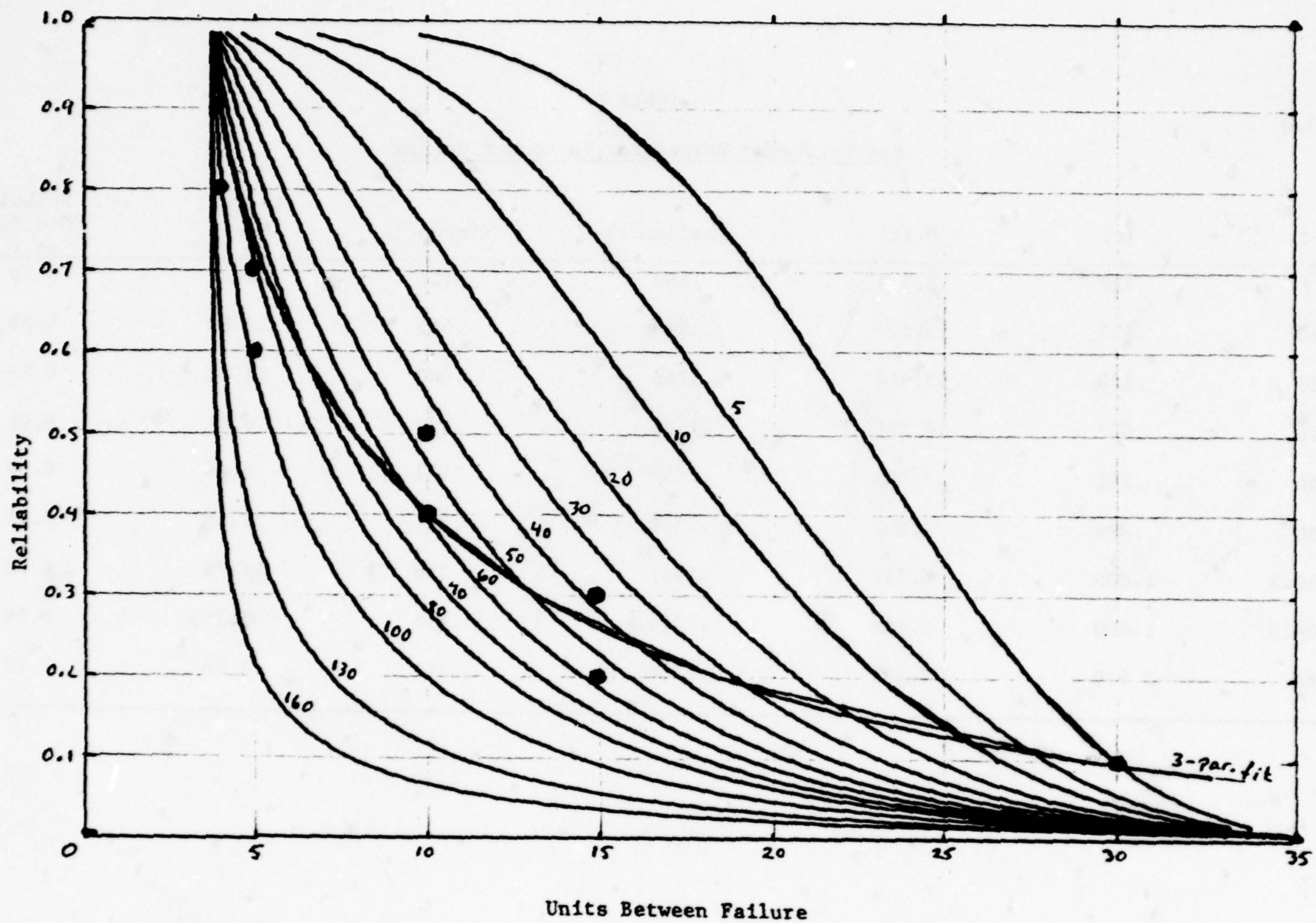
Variable	Intercept	ln t	ln x	ln t ln x
Simple Correlation	1.0	.939	.553	.401
		1.0	.332	.364
			1.0	.818
				1.0
Coef	-11.3103	2.3016	3.7208	-0.6659
Pseudo Multiple Correlations	.9998	.9998	.9996	.9993
Condition Number	.149-04			
Residuals:	Mean = -.1956-05			
	SEOE = .1085			

TABLE 6

Key Parameter Values for Various t Values

t	(t)	θ (t)	(median/t)	R(mean/t)	Weibull Mean at t	Weibull Std Dev at t
8	.428	16.327	.1160	.471	14.47	6.58
10	.457	15.607	.1149	.465	13.82	6.66
20	.579	12.913	.1146	.440	11.51	6.87
30	.687	10.931	.1188	.420	9.91	6.91
40	.791	9.303	.1259	.402	8.64	6.88
50	.896	7.901	.1359	.384	7.59	6.81
59.5	1.000	6.727	.1487	.368	6.73	6.73
104.5	1.600	2.653	.2935	.286	3.793	6.34
160	2.930	0.338	2.0504	.167	1.86	7.73

Graph 1. Reliability Curves Conditioned on Usage



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TITLE: Cost and Schedule Risk Analysis Modeling for Weapon System Acquisition Programs

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ABSTRACT: In order to insure that the Army of the 80's is properly equipped with weapon systems reflecting current technology, a continuing stream of basic research and development and new hardware development programs will be required. Funds for R&D programs continue to be scarce, and the programs are plagued with uncertainties inherent to such development efforts.

Uncertainties associated with project costs, schedule, and probability of successful completion need to be addressed. The decision maker is also interested in alternative approaches, a comparison of risks for each alternative, and potential trade offs that can be made to minimize these program risks. A methodology and a simulation program, designed to address these problems, are discussed. A weapon system risk analysis modeling application is also discussed.

Cost and Schedule Risk Analysis Modeling
for Weapon System Acquisition Programs

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Missile Research and Development Command

I. INTRODUCTION

Cost growth in new weapon systems has probably received more attention in the media during the past several years than any other defense subject. The General Accounting Office (GAO) cites that three principal causes of cost growth are increases resulting from greater capability demanded of new systems which then requires a greater system complexity; increases resulting from the way weapon system programs are managed from the design and development stage through production; and inflation (4, p. 1).

To meet the constantly increasing military capability of enemy hardware and to exploit new technology, military services require that new weapon system capabilities exceed those to be replaced. Hence, today's weapon systems are much more complex and, therefore, more costly than their predecessors. A comparison of the latest generation of eight systems such as aircraft, missiles, and tanks shows that the cost of each successor system is between two and six times greater than its predecessor (4, p. 17).

Managers of Weapon System development programs have had a difficult task trying to control system changes and attempting to achieve what are often very optimistic cost, schedule, and performance requirements. Cost histories of 45 systems under development in June 1972 showed that estimates one year later exceeded development estimates by 20 percent ($19.1 Billion) (4, p. 24). Such widely publicized overruns have had a severe impact on the credibility of both government and industry management. One case, the C-5A nearly doubled its estimated unit cost from $28 to $55 million dollars over a five year period (4, p. 24). Such cost growth experience is not new. A Harvard research team analyzed 12 weapon system development programs in the 1950's and found that development costs averaged 3.2 times the original estimate, and schedule slippage averaged 1.36 times the original estimate (13, pp. 429-430).

The GAO cites three primary contributors to cost growth due to acquisition management. These are inflation, changes to specifications, and inaccurate estimating (4, pp. 25-29). Inflation has had a massive impact on the Department of Defense (DOD) budget. While actual expenditures from FY 54 to FY 74 have increased by 81%, the FY 74 budget is 20% below the FY 54 level in real buying power. Key elements of weapon system costs have escalated dramatically the past few years. Metals and metal products escalated 50% from 1972-1975. Fuels and related products escalated 100% during the same period (20). An accurate representation of future defense expenditures, which includes the differing impact of inflation on separate segments of the economy, is critical to both the DOD budgeting process and to the development of credible cost estimates. Development of DOD price indices and their use in weapon system cost estimating are discussed by Howard (10).

Cost growth due to changes in specifications (schedules, quantities, or engineering changes) primarily results from unrealistic performance targets at the outset. These include challenging the state-of-the-art- frontier and trying to develop and produce the system too fast (4, p. 29) or not starting R & D soon enough. As a result production is started before development is complete. Stringent performance requirements, combined with optimistic risk estimates and low initial cost predictions, lead to engineering changes, cost growth and schedule slippages.

The third cause of cost growth, cited by the GAO, is inaccurate estimating. Forces of competition are a major cause of optimistic estimates by defense contractors. Other inaccuracies result from the difficulty of estimating unknowns and predicting technology. These areas will always be a problem for cost estimators. The Blue Ribbon Defense Panel reported that:

> The implicit assumption that technical risks can be foreseen prior to commencement of development has proved wrong. * * * It follows that the belief that detailed pricing techniques for the total system acquisition effort can be accomplished during contract definition is equally false. Only gross pricing techniques such as parametric pricing are likely to provide forecasts of ultimate costs of weapon systems (2, p. 2).

The Army has exhibited a growing concern regarding its capability to develop credibile weapon system cost and schedule estimates and to assess research and development program risks. Cost analysis capabilities were established at all Army Materiel Development and Readiness Command (DARCOM) Major Subordinate Commands in the late 1960's. In the early 1970's a series of courses[1] were developed to improve the capability of Army personnel in both cost analysis and risk analysis. A general methodology was developed to assess weapon system development program risks.

II. WEAPON SYSTEM DEVELOPMENT PROGRAM RISK ANALYSIS METHODOLOGY

Background

Many approaches have been explored to provide government and industry program managers with information that will enable them to program and manage costs effectively. However, in the past these tools have not adequately addressed the uncertainty associated with program cost, schedule, and performance estimates. The approach for handling uncertainty, that has gained considerable impetus in the Department of Army, is risk analysis/decision risk analysis. A discussion of weapon systems development program technical uncertainties will be followed with definitions of risk analysis and decision risk analysis.

In testimony to Congress (19, p. 2498-2499), Dr. M. B. T. George, Vice President, AVCO Corporation, examined technical uncertainty by partitioning states of knowledge into three classes - knowns, known-unknowns, and unknown-unknowns. The definitions and examples of these terms are shown below:

- Knowns - Things believed known and already resolved.
- Known-Unknowns (UNKS) - Things which are known to need resolution. For items in this class it is possible to estimate the effort required to resolve these into knowns.
- Unknown-Unknowns (UNK-UNKS) - Things which need resolution but which are unanticipated. By definition it is impossible to predict specific UNK-UNKS.

Examples of each of the classes of uncertainty are:

Known-Unknowns - An example of this would be the design and fabrication of a new airplane wing built along conventional lines.

Unknown-Unknowns - An example is catastrophic instability of early large liquid-fueled rockets. This was caused by

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[1]The courses are Cost Analysis for Decision Making, Cost Estimating for Engineers, and Decision Risk Analysis. They are taught at the Army Logistics Management Center, Fort Lee, Virginia.

fuel sloshing. No one anticipated this problem, because such rockets had not been flown before.

Figure 1 illustrates the changes in states of knowledge over the life cycle of a new program. If you investigate a time slice during the conceptual phase, there are relatively few known quantities, there are a lot of known-unknowns for which resources can be programmed; and there is a significant potential for unknown-unknowns as one would expect in this early phase of the life cycle. If you investigate a time slice late in full scale development, the knowns have increased significantly as a result of extensive design effort and engineering testing; the known-unknowns are reduced and the UNK-UNKS are reduced. But, there is still some finite potential for unexpected problems (UNK-UNKS).

Risk Analysis concerns itself with the modeling of the problem areas of cost growth, schedule slippage, and performance degradation which are caused to a great extent by these uncertainties inherent to a new weapon system acquisition program. The Army defines risk analysis (18) as a scientific approach involving the use of a large number of qualitative and quantitative techniques for analyzing and measuring the uncertainty associated with the cost, schedule, or performance goals of a system. Stated more simply by Webster, risk is the chance or danger of loss. Where there is uncertainty there is risk, and risk analysis is an attempt to quantify this uncertainty. Decision risk analysis (DRA) is closely related. Whereas a risk analysis attempts to quantify cost, schedule, and performance uncertainty associated with a specific program approach, a DRA considers alternative program approaches. Specifically, a decision risk analysis is the discipline of systems analysis, which in a structured manner, provides a meaningful measure of the risks associated with various alternatives, as presented to decision makers (28). As a minimum, a DRA must contain:

- A well defined problem.
- Alternative courses of action.
- An attempt to quantify the cost, schedule, and performance uncertainty associated with these alternatives.
- A clear, concise presentation to a decision maker highlighting the events to which the outcome of each alternative is sensitive.

A flow diagram for a decision risk analysis is shown in figure 2. The main point which can be drawn from this figure is that the Army performs a weapon systems analysis, with the added feature of emphasizing uncertainty.

Modeling Approach

The most common Army modeling approach for cost and schedule DRA's is probabilistic network analysis. Many Army analysts use a program entitled Risk Information System for Cost (and schedule) Analysis or RISCA (18). RISCA provides, as part of the output, a measure of cost and schedule uncertainty. This data, and its analysis is a subsequent part of any DRA.

To perform an analysis of a program using a RISCA approach, the analyst must first obtain from the system program manager and his representatives a PERT-type program layout—program activities and milestones with complete definition of interrelationships of activities. The program layout is then converted to a network utilizing RISCA modeling logic. It will be easier to discuss RISCA by discussing some of the drawbacks of PERT. Then the RISCA capability will be discussed in detail.

The typical PERT analysis assumes that the project will be completed and makes no provision for aborting the program. PERT uses "and gates" only and does not provide for situations where there may be many approaches

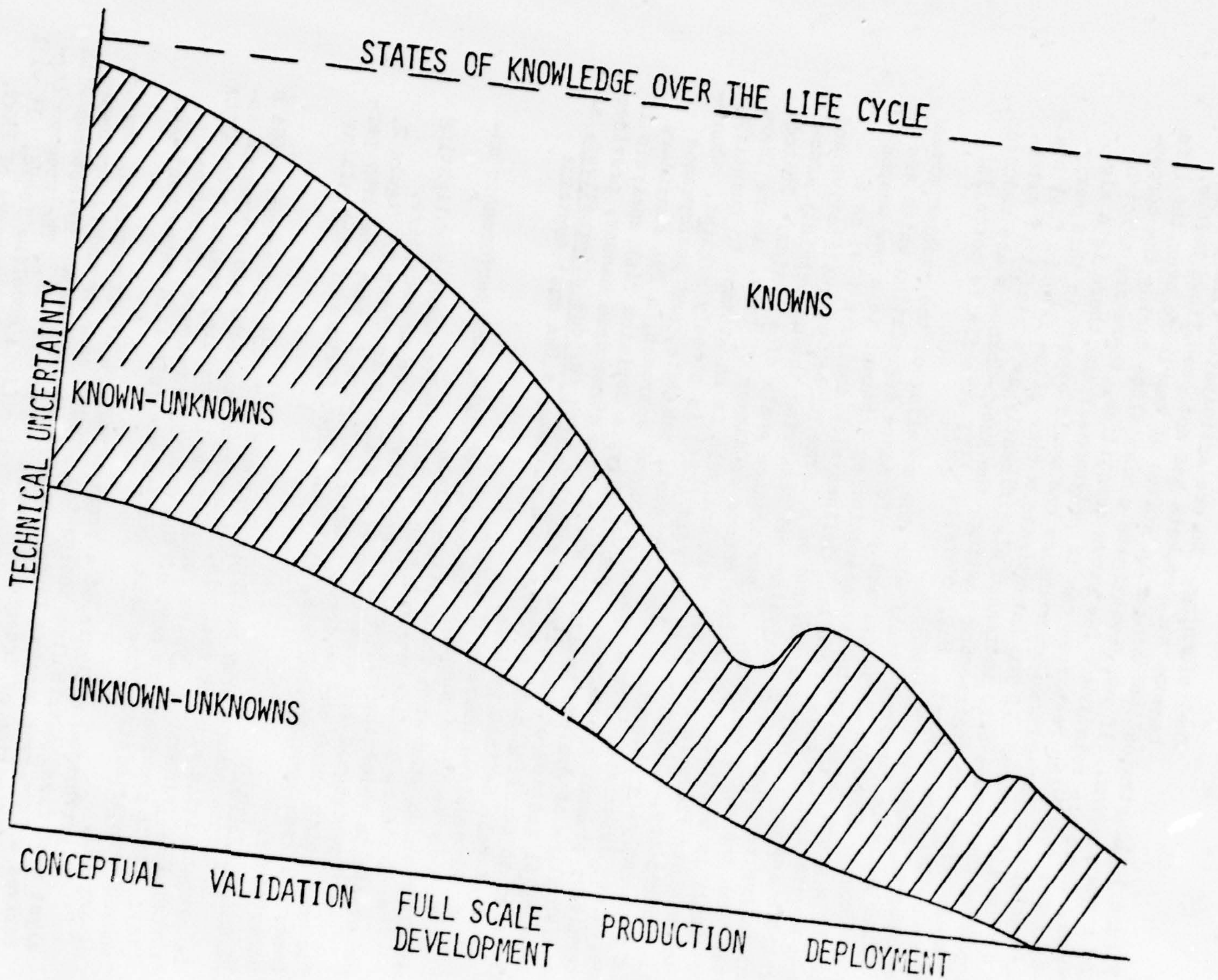
STATES OF KNOWLEDGE OVER THE LIFE CYCLE
KNOWNS
KNOWN-UNKNOWNS
UNKNOWN-UNKNOWNS
TECHNICAL UNCERTAINTY
CONCEPTUAL
VALIDATION
FULL SCALE DEVELOPMENT
PRODUCTION
DEPLOYMENT

FIGURE 1

DECISION RISK ANALYSIS

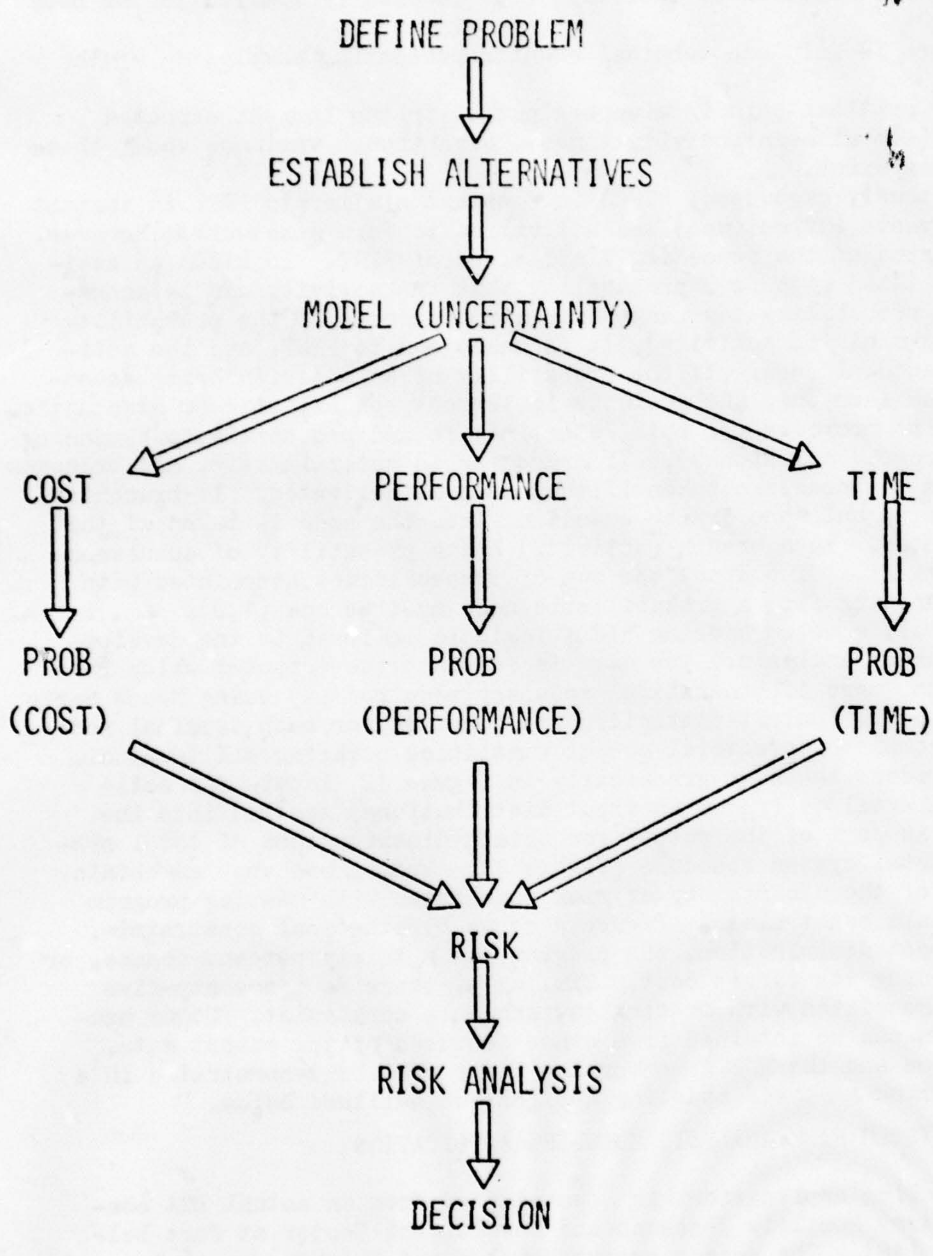

FIGURE 2

leading to the realization of an event. The typical R&D program often demands that a manager allow for more than one approach. Some basic limitations to PERT include the following:

1. All activities must be completed in order for the project to be completed (branching from a milestone or node, is "deterministic" - it must take place).

2. All activities must be completed before the event can be realized.

3. The distribution of activity times is usually limited to the Beta distribution.

4. There is only one terminal event representing completion of the project.

5. The critical path is always a path with the longest expected elapsed time (sum of mean activity times), even though variance about those mean times does exist.

As previously discussed, RISCA is somewhat similar to PERT in that it consists of events (milestones) and activities to form a network. However, it possesses none of the preceding limitations of PERT. In RISCA an activity has associated with it a probability that the activity can be accomplished. The probability may range from zero to one. If the probability is one (a deterministic activity), it is analogous to PERT, and the activity must be accomplished. If the probability of an activity being accomplished is less than one, the activity is termed probabilistic or stochastic.

RISCA also provides for both deterministic and probabilistic branching from nodes (program milestones). If branching is deterministic, all branches emanating from the node are taken if that node is activated. If branching is probabilistic, only one branch emanating from the node is taken if that node is activated. Each branch (activity) has a probability of occurrence associated with it. Of course, the sum of probabilities associated with activities branching from a probabilistic node must be one (1.0).

In general, a network using RISCA logic is tailored to the development program under analysis. The data is fed into the computer which runs 1000 iterations (more if statistical accuracy requires it) using Monte Carlo simulation methods. Output statistics are computed for each terminal node and also are combined into total output statistics covering all terminal nodes. The process is shown graphically in figure 3. Inputs for activities with uncertainty (shown as input distributions) are fed into the RISCA model. As part of the output you obtain distributions of total system cost and total system schedule (figure 3). From these you can obtain an indication of the uncertainty or risk associated with meeting program cost and schedule constraints. Figure 4 shows hypothetical constraints. Based on the cost distribution, the program has a thirty percent chance, or risk, of exceeding its target cost. Similarly, there is a seventy-five percent risk associated with meeting the schedule constraint. Other useful information can be obtained from other features of the output data. This information and the RISCA networking logic will be demonstrated in a weapon system risk analysis modeling application outlined below.

III. WEAPON SYSTEM RISK ANALYSIS MODELING APPLICATION

Background

The following application has been adapted from an actual DRA conducted by the Army Mobility Research and Development Center at Fort Belvoir, Virginia (18). The weapon system development program was an Armored Vehicle Launch Bridge (AVLB). Though the circumstances described and data given in this DRA application are not necessarily those actually encountered, the study illustrates the need for DRA data to enhance the program manager's decision making capability.

SIMULATION MODEL

(COST AND SCHEDULE UNCERTAINTY)

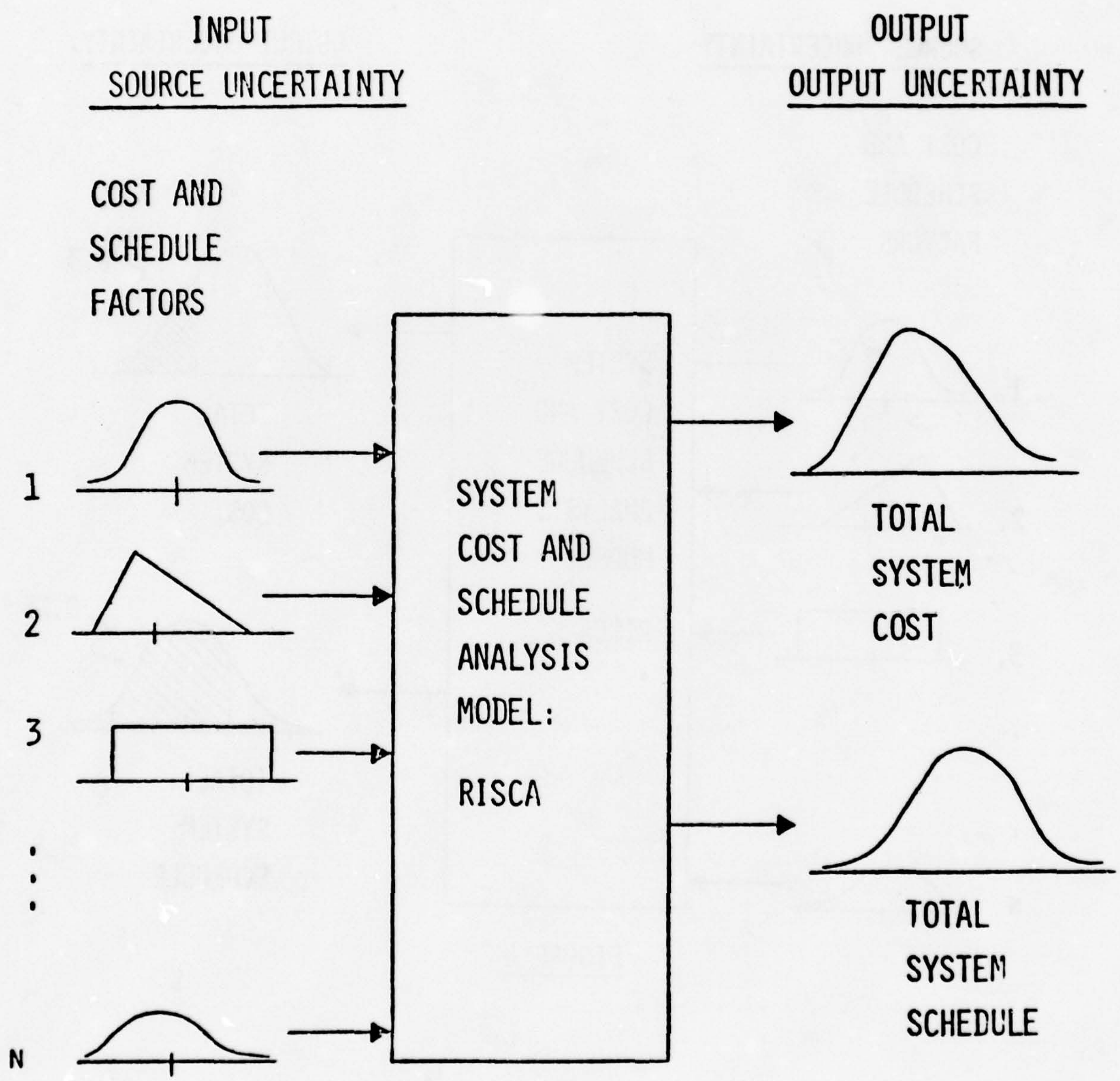

FIGURE 3

SIMULATION MODEL

(COST AND SCHEDULE UNCERTAINTY)

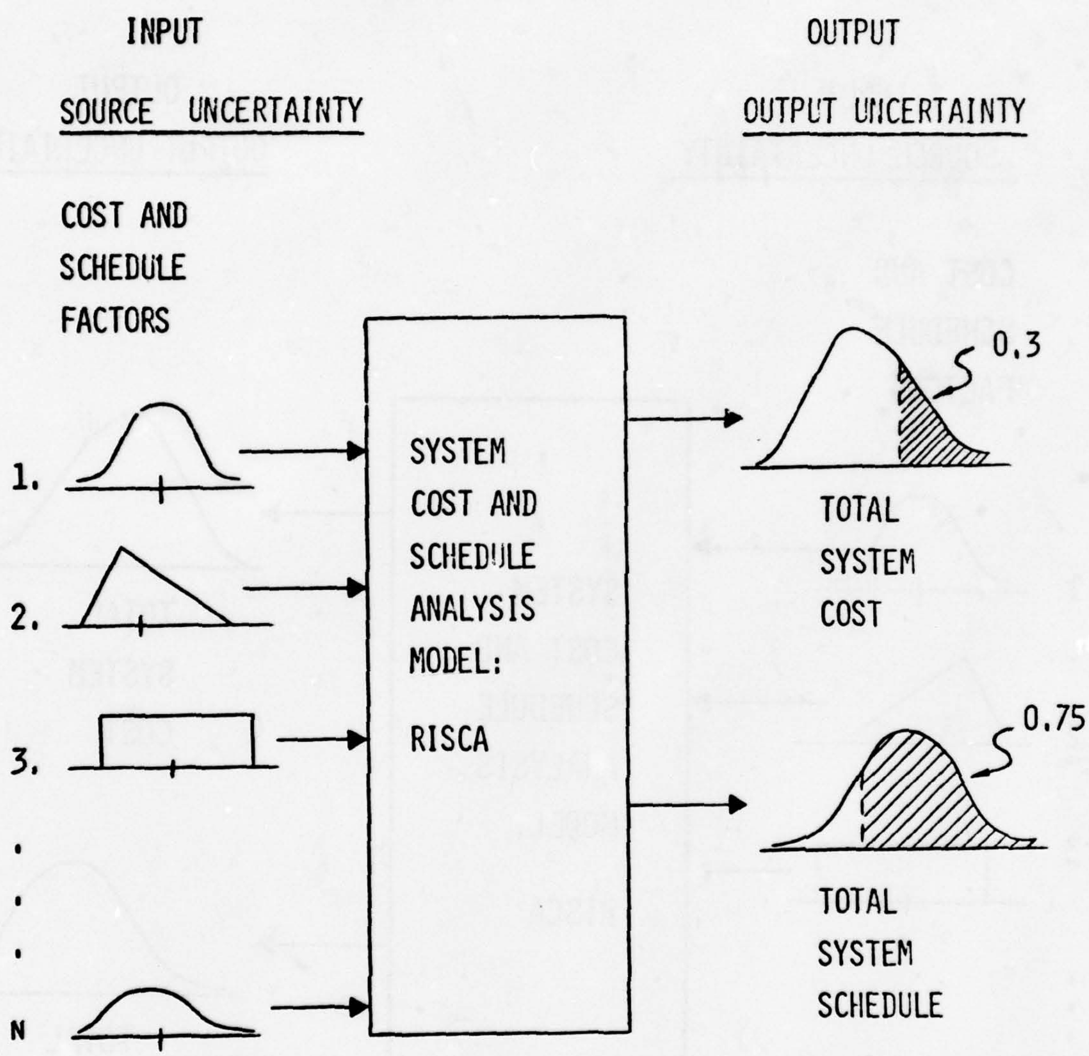

FIGURE 4

A previous study had established that for the time frame 1975-85, the best system to enable assault vehicles to cross gaps up to 90 feet in width would be a vehicle launched bridge. Since currently the only AVLB in the Army is 60 feet long, the risk analysis team was asked to evaluate several alternate proposals and project stagings for a 90 foot bridge. All bridge designs are based on use of three approximately 30 foot sections, constructed of a high strength aluminum; this material being required to satisfy weight and overturning moment constraints.

The team was immediately confronted with the problem of recommending the method of fabrication of this bridge. Most of the members agreed that from the standpoint of both cost and time, a welded design would be preferred. However, a vocal minority of the team strongly pointed out that welding of high strength aluminum was more art than science and high strength results could not be guaranteed. They further stated that even if successful welded prototypes could be achieved, there remained the problem of field repair; could troops in the field satisfactorily re-weld a bridge put out of commission? They suggested that the welded idea be abandoned for a 100% reliable (but more costly) riveted design.

Much information seeking was then undertaken in an attempt to narrow the areas of contention. Based on results of these investigations, it was finally agreed that there was a reasonable chance of successfully developing a high strength welded design. However, controversy then developed over the relative cost, time, and performance of the two designs. After more discussion, the risk team, with input from the program manager, developed four alternative program strategies to resolve the questions. (Note: It was evident to the team that should the welded construction pass preliminary testing, it would then be a virtual certainty that the welded design would be accepted, with time to acceptance being the unknown quantity. It was for this reason that the trial networks were first drawn out only as far as the Test and Evaluation Command (TECOM) prototype testing.) The four alternative program strategies are described below.

<u>Program Alternatives</u>

1. For the welded construction, the first step is the following: awarding the design contract, prototype fabrication, and preliminary testing. Now, should the tests be positive, further work is done on the welded construction. More prototypes of the welded version are required before TECOM begins to test them.

If preliminary testing proves unsuccessful, a riveted design will be employed. Again, starting at this time, the steps of design contract award, Prototype fabrication, and preliminary testing of the riveted design take place. Should the testing be successful (it is anticipated that the riveted design would present fewer technical problems than the welded), additional prototypes of this version will be necessary for TECOM test.

2. In this configuration, both designs are developed simultaneously. The first design to successfully complete preliminary testing is chosen. The other is abandoned.

3. This is similar to alternative 2 except the welded design is preferred. Though both designs are developed simultaneously, only in the case that the welded alternate fails preliminary testing will there be any further activity on the riveted design (This means that should the riveted design pass preliminary testing before this phase is completed for the welded design, all work on the riveted design is suspended pending results on the welded design, regardless of the delay.)

4. Similar to alternative 1 with the exception that a feasibility

study on welded construction must be conducted and successfully completed before the procedure described in alternative 1 is undertaken.

Should the results of the feasibility study be negative, work is initiated on a riveted design with requirements identical to that described in alternative 1.

In summary, the four alternatives to be analyzed are:

- Sequential development.
- Parallel development.
- Parallel development with the weld approach preferred.
- Feasibility study on welded construction followed by sequential development.

Methodology and Data

The risk data (probability of completing an activity, activity time distributions, etc.) for AVLB activities were collected and are summarized in Table 1. The four alternative program strategies were networked using RISCA logic (figures 5, 6, 7, and 8). A brief discussion of the network for alternative 1 (figure 5) follows.

The program is initiated (NODE 1). ARC 1 represents the activity "Welded construction contract award, prototype fabrication, and preliminary testing." Note that the data for ARC 1 come from the risk data summarized in Table 1. Let's examine the data on ARC 1. The time distribution for the activity is triangular with parameters 8-20-34 (8 months optimistic, 20 months most likely, and 34 months worst case). The cost function for the activity (in thousands of dollars) is

$$\text{Cost} = 310 + 15\,t$$

The "310" represents $310,000 of fixed costs. The "15t" represents $15,000 per month of time-variable costs. The value for "t", that is input into the cost equation, is obtained by sampling a time value from the time distribution (8-20-34).

For example, if on the first iteration of the computer simulation a value of ten months is sampled for "t", then the cost to accomplish the first activity (ARC 1) is

$$\begin{aligned}\text{Cost} &= 310 + 15\,(10)\\ &= 310 + 150\\ &= \$460 \text{ thousand dollars}\end{aligned}$$

for that iteration. The process, of course, continues for 1000 iterations, and the computer stores the time and cost values obtained for each iteration. These values are combined with costs and times of the other activities. When grouped and printed out, they form the total cost and total schedule distributions discussed in connection with figures 3 and 4.

The last piece of information on ARC 1 is the probability of activity success (0.75). This, like the time distribution and cost function, is a subjective estimate.

If ARC 1 is successfully completed, the program proceeds to ARC 2 and ARC 3 and terminates in NODE 4. Hence, NODE 4 represents successful completion of a welded design. However, if the first weld activity (ARC 1) is unsuccessful (0.25 chance of occurrence), the program proceeds to ARC 4 representing the activity "riveted construction award, prototype fabrication and preliminary testing." If ARC 4 is successfully completed, the program proceeds to ARCs 5 and 6 and terminates in NODE 7. Hence, NODE 7 represents successful completion of a riveted design. However, if ARC 4 is unsuccessful (0.10 chance of occurrence), the program proceeds to ARC 7 (a dummy activity) and terminates in NODE 8. Hence NODE 8 represents program failure. The networks for the other alternatives can be analyzed similarly.

TABLE 1

DATA FOR RIVET AND WELD ACTIVITIES

Activity	Probability of Success in Activity if Feasibility Study is Conducted (Alternative 4)	Probability of Success in Activity	Time (Months)	Cost
Welded construction contract award, prototype fabrication, and preliminary testing	.966	0.75	8-20-34	310+15t
Additional welded prototype construction	1.0	1.0	9-11-13	490+15t
TECOM tests welded prototypes	1.0	1.0	9-15-27	0+15t
Riveted construction contract award, prototype fabrication, and preliminary testing	0.9	0.9	21-33-47	445+15t
Additional riveted prototype construction	1.0	1.0	9-11-13	575+15t
TECOM tests riveted prototypes	1.0	1.0	9-15-27	0+15t
Feasibility study of welding	0.7375	N/A	2-3-4	0+25t

ALTERNATIVE 1

SEQUENTIAL DEVELOPMENT

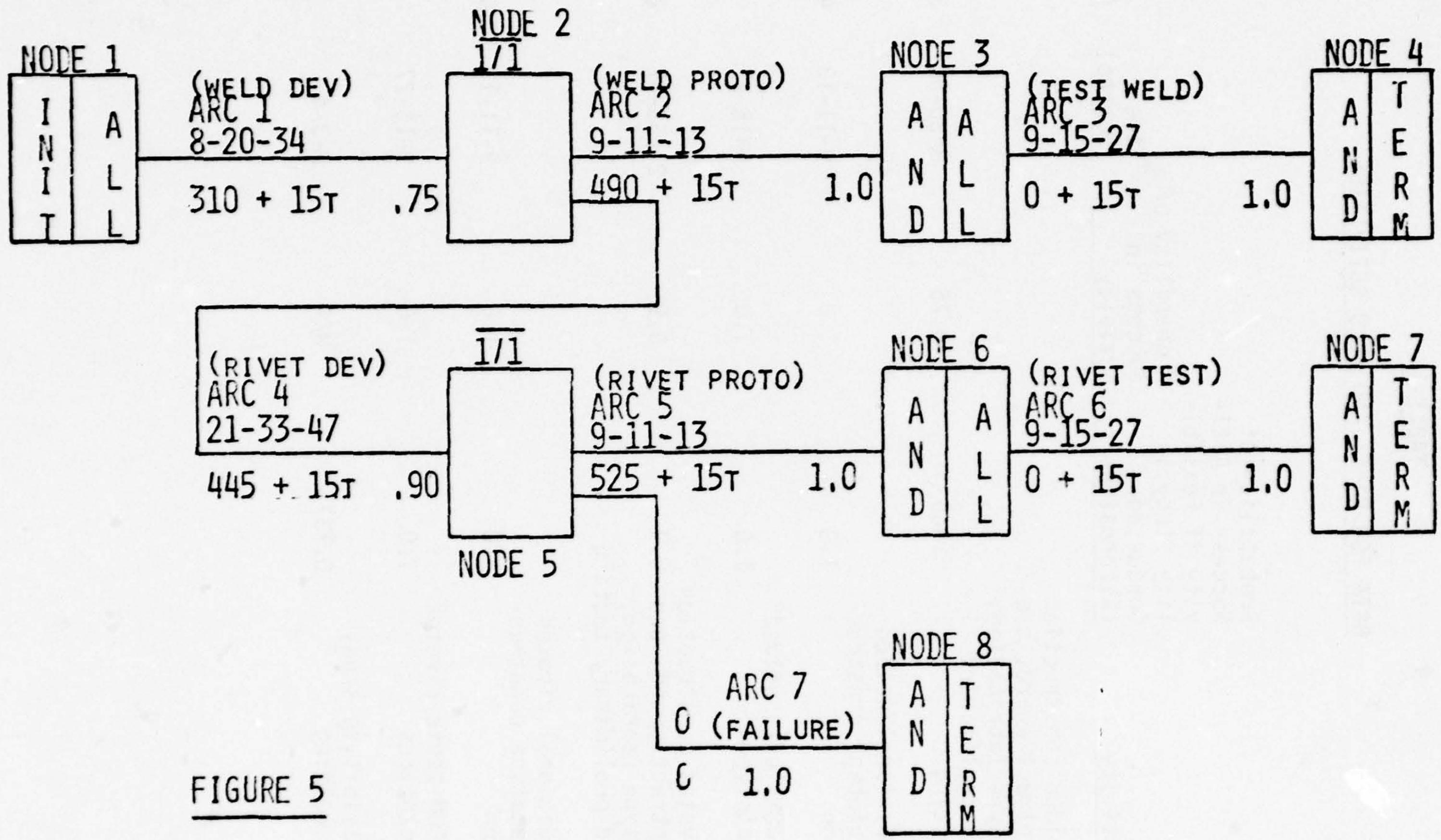

FIGURE 5

ALTERNATIVE 2

PARALLEL DEVELOPMENT

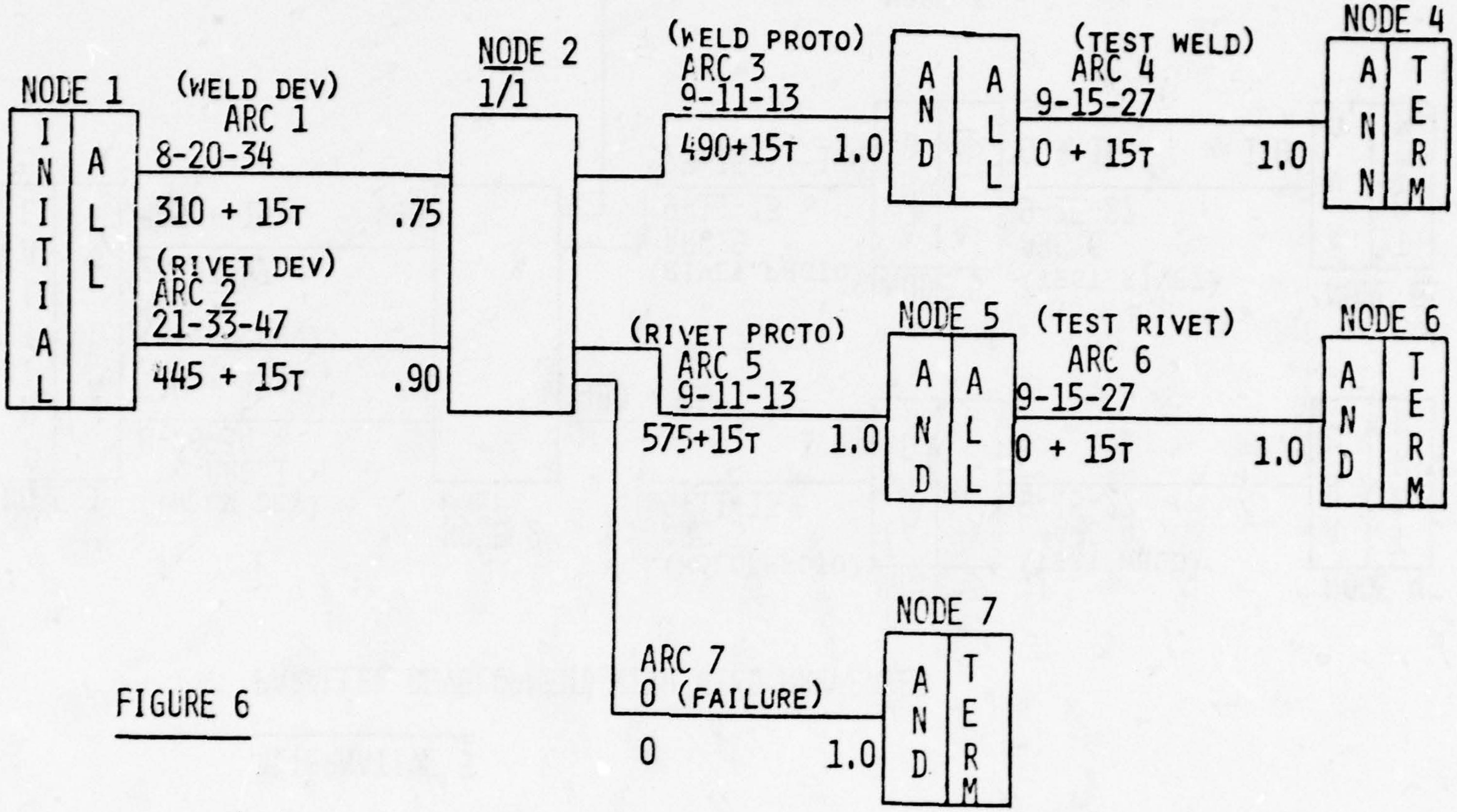

FIGURE 6

ALTERNATIVE 3

PARALLEL DEVELOPMENT WITH WELD PREFERRED

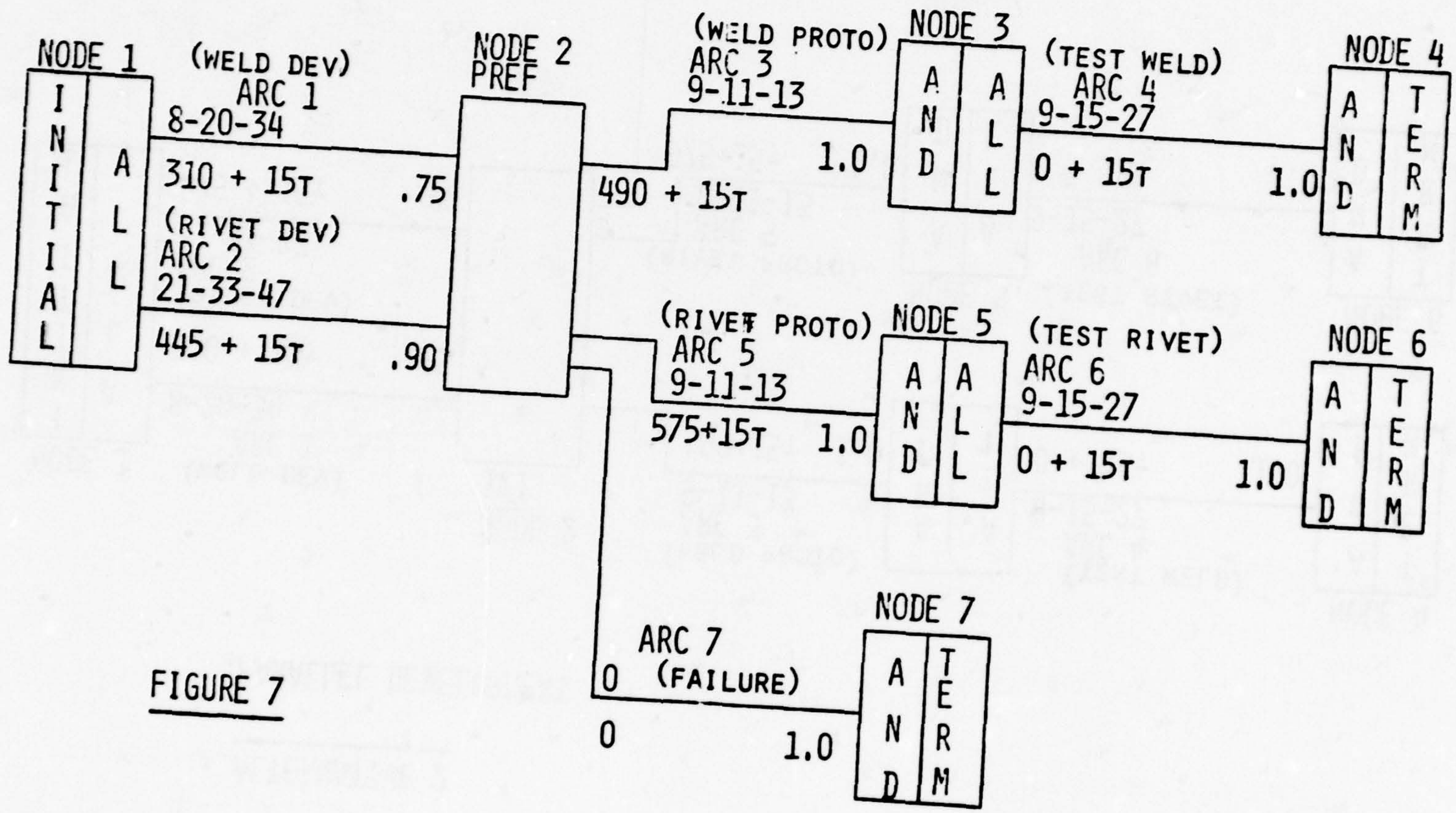

FIGURE 7

ALTERNATIVE 4

FEASIBILITY STUDY
FOLLOWED BY SEQUENTIAL
DEVELOPMENT

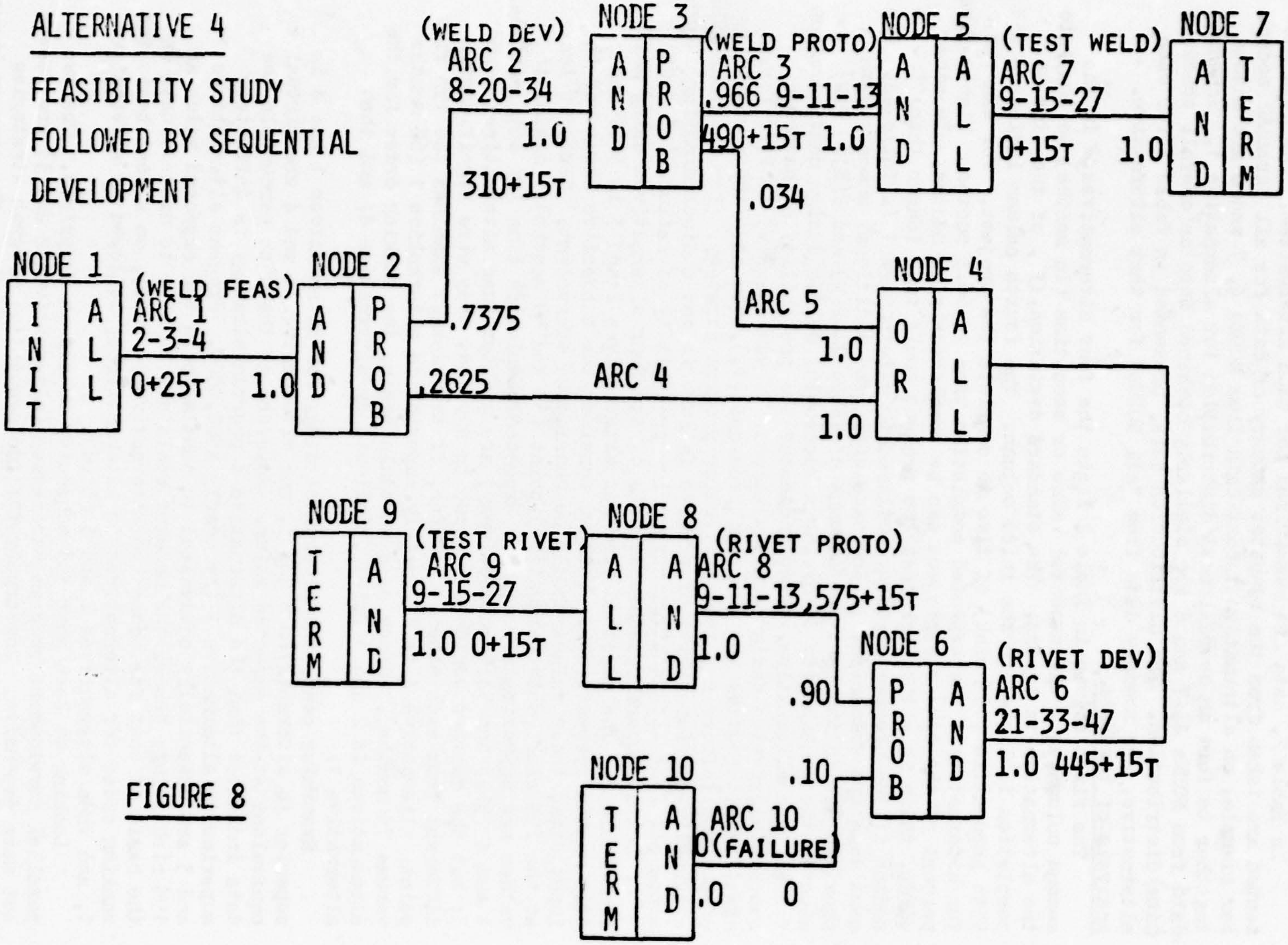

FIGURE 8

In Table 2, data are summarized for each alternative. The data presented are taken from the computer summary of data for all terminal nodes. For example, an alternative 1 cost data from NODEs 4, 7 and 8 are summed together to form an overall cost distribution for alternative 1. Schedule data from NODEs 4, 7 and 8 are similarly combined into an overall schedule (time) distribution. The distribution data, presented in Table 2 for each alternative, are summary data from "all NODEs" for that alternative.

Analysis of the Data

The first column in Table 2 lists the four alternatives. In the second column, μ , the expected value or mean time (in months) to complete the alternative is listed. The standard deviation, σ, of the time to completion is listed in the third column. The fourth column indicates the 85th percentile (15% risk) of time to complete the project. For example, for alternative 1 the expected completion time is 56.3 months. Eighty-five percent of the time the project can be completed by 75 months. In other words, there is a 15% risk that the project could take longer than 75 months if the program strategy outlined in alternative 1 is followed. The cost data are summarized in the same way. The additional summary data provided are in the last two columns of Table 2—P(W) and P(R). P(W) indicates the probability of having a successful welded design configuration for a given alternative. P(R) indicates the probability of having a successful riveted design configuration. If you add P(W) to P(R) for a specific alternative and subtract from one (1.), you have the probability of program failure for that particular program strategy. For the four AVLB alternatives, probability of program failure is not a discriminating factor since all four alternatives have a low probability of failure (≤ 0.04).

Let's compare schedule aspects of the four alternatives using data from Table 2. The expected time for alternatives 2 and 3 is 50.9 and 51.8 months respectively. When we consider the subjective nature of the input data, these values should be considered equivalent. Next, we look at the 15% risk (85th percentile) point (58 and 59 months). Again, the values are approximately equal. Expected completion time for alternatives 1 and 4 (56.3 and 54.9 respectively) are greater than alternatives 2 and 3; but the manager would be pressed to say that they were significantly different from each other. However, if the manager examines the 15% risk point, alternative 4 is definitely superior to alternative 1 (62 months versus 75 months). Hence on a schedule basis, the ranking order for the alternatives is 2 and 3 (tied), followed by alternative 4, and then alternative 1.

Examining cost, the program strategy for alternatives 1 and 4 is superior to alternatives 2 and 3, and alternatives 1 and 4 are virtually equivalent at the expected value. However, at the 85th percentile the data indicates that the alternative 4 program strategy is definitely superior to alternative 1 (by nearly $500,000). Program alternatives 2 and 3 are essentially equivalent in cost at both the expected value and 15% risk point; hence, the manager would not be able to discriminate on the basis of cost for those two alternatives. Hence, on a cost basis the ranking order for alternatives is alternative 4, followed by alternative 1, and then alternatives 2 and 3 (tied).

Looking at both cost and schedule, we see no surprises. The two parallel development program strategies (alternatives 2 and 3) are faster but more expensive. Conversely the two sequential program strategies (alternatives 1 and 4) take longer but are less costly. The manager knows these facts without a decision risk analysis; however, with a DRA he has the data necessary to make cost versus time trade offs. For example, when

TABLE 2

ARMORED VEHICLE LAUNCHED BRIDGE

SUMMARY DATA FOR ENTIRE NETWORK ("ALL NODES")

	TIME (MONTHS)			COST (K $)			PROBABILITIES *	
ALTERNATIVE	μ	σ	85TH PERCENTILE	μ	σ	85TH PERCENTILE	P (W)	P (R)
1	56.3	16.4	75	1759	437	2435	.76	.21
2	50.9	8.9	58	2470	209	2580	.72	.25
3	51.8	8.7	59	2490	182	2580	.73	.24
4	54.9	9.8	62	1705	262	1930	.72	.24

* THE VALUES SHOWN FOR P(W) AND P(R) ARE SIMULATED PROBABILITIES AND THEREFORE DIFFER SLIGHTLY FROM THE TRUE CALCULATED PROBABILITIES.

we examine expected cost and expected time values for alternatives 2 and 4, is it worth $765,000 to save four months on the total program? If we have a hot item for a Middle East conflict, maybe it is. A DRA puts the manager in a posture to make this type of comparison and evaluation of cost and schedule for all alternatives under consideration.

IV. SUMMARY

Decision risk analysis, as currently used in the Army, is a tool for management which, if properly used, can be an invaluable aid for decision making. DRA encompasses a large number of techniques, qualitative and quantitative, which in themselves are not new. Quade and Boucher (14, p. 2) in 1968 defined systems analysis in terms that are equally appropriate for Army DRA's. Their definition is:

> A systematic approach to helping a decision maker choose a course of action by investigating his full problem, searching out objectives and alternatives, and comparing them in the light of their consequences, using appropriate framework - in so far as possible analytic - to bring expert judgement and intuition to bear on the problem.

Raiffa (15) makes the observation that the creative stage in an analysis may be the stage in which the decision maker decides he has a problem and decides to consider it in earnest. He further states that in complicated problems, the mathematical part of the analysis is not necessarily the most intellectually challenging or important part. Army managers can relate to the significance of Raiffa's observations, and they realize that decision risk analysis is not a panacea for all problems associated with new development programs. However, it is an important methodology that can provide better information than has typically been available to the decision maker. If understood and used correctly, cost and schedule risk analysis modeling can continue to improve Army management decision making on weapon system acquisition programs.

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TITLE: A Study of Potential Savings from NATO Standardization

AUTHOR: Mr. Earl Williamson

ABSTRACT: Although greater economies of scale in weapons production are recognized as one of the advantages of NATO standardization, few efforts have been made to quantify the magnitude of these savings. In this paper, cost quantity relations of the "learning curve" type are applied to the three most pervasive land combat systems: tanks, personnel carriers, and self-propelled artillery. Application of an assumed generic type learning curve to quantities implied by a NATO standard procurement yields an index of potential savings when compared with the cost of a series of national-size buys.

Learning is assumed to be 90 percent, and first unit costs are drawn from US procurement experience. The cost of redundant R&D efforts is also estimated based on US experience. All national R&D efforts except one for the same type system are assumed redundant.

Procurement savings are applied to the portion of battalion operating cost which is replacement parts and assemblies to yield annual operating cost savings.

SUBJECT: A Study of Potential Savings from NATO Standardization

AUTHOR: Mr. Earl Williamson

AGENCY: USA Concepts Analysis Agency

I. Introduction

A. It is generally conceded that standardization of NATO weapons would lead to significant savings in equipment acquisition through avoidance of duplicate development and through economies of scale from larger production quantities. No studies have been performed which estimated these savings without directly resorting to judgemental factors.

B. In March 1977 Concepts Analysis Agency (CAA) undertook to estimate the potential magnitude of such savings to accompany a study of the effects of NATO standardization on battle outcome. Since the time available precluded the collection of actual data on the cost of foreign weapon systems, it was decided to use an abstract methodology which would analyze the effect of NATO-wide quantities on a simple learning curve model.

II. Methodology

A. General. The general methodology of the study is to select several types of systems and to estimate the potential savings which NATO standardization could achieve based on elimination of duplication in R&D and on consolidation of production. The estimates are based on a logical extension of a general cost-quantity function assumed to exist for each system.

B. Systems Selection. Three types of systems were selected for analysis: tanks, personnel carriers, and medium self-propelled artillery. These three systems represent 20% of the asset value of all combat equipment and theater support equipment, based on data collected for the TRANSFORM study.* These items were selected because they represent the major land combat systems in terms of value and because at least four NATO nations have the capability to develop and produce these systems. Items such as high-altitude air defense missiles, attack helicopters, and air defense radar were excluded because of a substantial US technology advantage. Items such as small arms, trucks, and ammunition were excluded because they are produced by several nations in sufficient quantities that gains from consolidating all NATO procurement are not as certain.

C. R&D. Savings in R&D are estimated as the cost of redundant development efforts within each system category. R&D costs for a system are assumed equal to the latest US effort.

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*(S) Trade-Off Analysis System/Force Mix (TRANSFORM) (U), CAA-SR-77-4, 15 Aug 1977.

D. Procurement Costs. Procurement savings are estimated as the difference between the cost of manufacturing each nation's quantity of systems, derived through separate cost-quantity functions, and the cost of manufacturing the corresponding cumulative quantity of systems, represented as a single cost-quantity function for complete standardization, or two functions for co-production. A generic cost-quantity function which assumes 90% learning is used for each type of system.

E. Operating Costs. Only those operating cost savings attributable to reduced spare parts costs from larger scale production are included as operating savings in this study. These savings were based on extension of procurement cost savings to the estimated annual recurring costs for major equipment and repair parts in the Army Force Planning Cost Handbook.**

III. R&D Savings. For the three systems studied total estimated potential R&D savings are slightly over $2 billion. One obstacle to achievement of these savings is the different obsolescence cycles of the US and Europe. These savings are detailed below.

A. Tanks. During the early 1960s the AMX-30, Chieftain, and Leopard were all developed nearly simultaneously. Estimating a tank development effort at $500 million, at least $1 billion was redundant to France, Britain, and the FRG, to say nothing of the US efforts which are on a different cycle. Had France, Britain, and the FRG used the M-60 until a combined effort in the mid-1970s could develop a single tank, then $1.5 billion might have been saved.

B. Personnel Carriers. During the period 1955 to 1980 NATO will have developed six full-tracked armored personnel carriers. At least two efforts would have been necessary due to the 25 year period under consideration. Estimating an armored personnel carrier program to be $150 million, and assuming four of these efforts could have been avoided through standardization, $0.6 billion might have been saved.

C. Self-Propelled Howitzers. The only redundant R&D effort in medium self-propelled howitzers was the French F-3, which probably cost less than $50 million. The British Abbot was redundant to the US M108 105mm (light howitzer), but it is difficult to say that the M109 could be substituted for the Abbot because of the British choice of a mix of self-propelled light and medium howitzers.

IV. Procurement Savings. Maximum potential procurement savings from standardization, for the three items studied, which represent 20% of the value of theater level equipment, are $1-1/2 billion. These savings are detailed below.

**Published annually by the Office of the Comptroller of the Army.

A. Tanks. During the period 1960-1980, NATO will have produced over 10,000 main battle tanks. The total cost of separate production runs is estimated at \$4.4 billion using a generic cost-quantity function of: Cost = \$1.20 million x $(\text{quantity})^b$; where b is the coefficient of 90% learning. A single production run evaluated on this same cost-quantity function would have cost \$3.5 billion, indicating savings of \$0.9 billion (20%). Savings from co-production would be \$0.5 billion.

B. Personnel Carriers. During the period 1960-1980 NATO will have produced over 16,000 full tracked personnel carriers. The total cost of separate production runs is estimated at \$1.6 billion using a generic cost-quantity function of: Cost = \$0.3 million x quantity^b; where b is the coefficient of 90% learning. A single production run evaluated on this same cost quantity function would have cost \$1.3 billion, indicating savings of \$0.3 billion (19%). Savings from co-production would be \$0.2 billion.

C. Medium Self-Propelled Howitzers. Nearly complete standardization was achieved by NATO in medium self-propelled howitzers except for the French F-3. All other nations utilize the US M109/M109A1. Had Britain and Germany produced their own weapon for their national requirements, the total cost of the separate production runs would have been \$0.96 billion, based on a generic cost-quantity function of: Cost = \$1.3 million x quantity^b; where b is the coefficient of 90% learning. A single production run evaluated on this same cost quantity function would have cost \$0.80 billion, indicating savings of \$0.16 billion (17%). Savings from co-production would be \$0.07 billion which approximates the savings actually achieved in this system.

V. Operating Cost. The savings which would accrue to each US tank battalion, mechanized infantry battalion, and field artillery battalion were estimated by taking the percentage savings, obtained in the discussion of procurement savings above, and applying this percentage to the annual cost of replacement equipment, repair parts, and Program 7 and 8 OMA support and MOS training costs for each type US battalion. These costs were obtained from the Army Force Planning Cost Handbook, June 1975. The savings per battalion per year are then extended to the apparent number of battalions in NATO. Potential NATO operating savings are about \$270 million per year.

A. Tanks. Recurring procurement of major equipment and repair parts for a US tank battalion in Europe is \$3.2 million per year. If 20% savings could be realized from consolidation of procurement, then \$0.64 million could be saved annually in each battalion. Assuming 150 tank battalions in NATO, total savings would be \$96 million per year.

B. Armored Personnel Carriers. Recurring procurement of major equipment and repair parts for a US mechanized infantry battalion in Europe is \$0.6 million per year. If 19% savings could be realized from consolidation of procurement, then \$0.11 million could be saved annually in each battalion. Assuming 175 mechanized infantry battalions in NATO, total savings would be \$20 million per year.

C. Self-Propelled Howitzers. Recurring procurement of major equipment and repair parts for a US artillery battalion is \$0.9 million per year. If 17% savings could be realized from consolidation of procurement, then \$0.153 million could be saved annually in each battalion. Assuming 100 NATO medium self-propelled artillery battalions, total savings would be \$153 million per year.

VI. Nature of Economics to Scale. This study utilized a 90% learning curve to model the benefits from larger production quantities. According to economic theory the benefits of larger quantities stem from many factors, some of which are: the amortization of set up costs, more efficient utilization of equipment having fixed capacities, and specialization of labor. It should be noted that these efficiencies are returns associated with both the length of the production run (learning), and the rate of production.

VII. Summary. The designation of a single source to develop and produce each major type of weapon system could save as much as \$3 billion in the case of tanks, during a 10 year tank acquisition cycle. This is based on two key assumptions; larger production quantities benefit from economies similar to those modeled by a learning curve, and a single weapon development effort would provide NATO with an adequate quality of weapons.

TITLE: Applicability of Zero Base Budgeting to Army R&D Laboratories

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ABSTRACT: Zero Base Budgeting is part of the future in the federal government and it is important to understand what it purports to do and how this is achieved. ZBB is applied to overhead costs in the private sector and to programs providing public services at all levels of government. But can it contribute in defense R&D which has already received substantial attention in terms of the resource allocation problem? The paper describes a bottom-up approach to applying ZBB at the work unit level. The emphasis is on ZBB as a marginal analysis budget tool using the decision package as the decision maker's instrument for working the benefit-cost calculus. The relationships between decision packages, work units and projects are described and a model for project prioritization is given. The application of this model to the FY-78 program in the authors' laboratory demonstrates that the application of all the essential elements of ZBB is necessary to optimize the benefit of the laboratory program.

APPLICABILITY OF ZERO BASE BUDGETING TO ARMY R&D LABORATORIES

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INTRODUCTION

Recent budget pressures have forced defense laboratories to adopt more stringent control of budgets and to develop improved techniques to implement the process of allocating scarce resources. In the light of one laboratory's experience it looks as if it will be necessary to apply the full range of concepts which are considered to be the basic elements of zero-base budgeting in order to optimize the benefits of the total program. Before we can expect to be able to present this case effectively, it is important to clarify some concepts relating to zero-base budgeting and, perhaps, clear away some misconceptions about it. Simply, zero-base budgeting may seem to imply the **annual** construction of the budget of an organization without any reference to the past and with equally detailed attention to all programs. Of this view Graeme Taylor (1) quotes Allen Schick as saying, "Even a teenager doesn't have an identity crisis every year" and Dean Acheson's remark in another context, "We can't have a foreign policy if we pull it up every year to examine its roots."

Several years before Peter Pyhrr, Texas Instruments, the Harvard Business Review and a former governor of the State of Georgia became linked together with zero-base budgeting, the U.S. Department of Agriculture issued an instruction for the preparation of the FY64 budget. "...all programs will be reviewed from the ground up and not merely in terms of changes proposed for the budget year."(2) An analysis of the result of this approach failed to credit it with much impact on the budget (loc. cit.).

While zero-base budgeting does require a comprehensive budget justification as opposed to approach which focusses attention on program increments exclusively, a more meaningful definition emphasizes the role of marginal analysis in zero-base budgeting.

The essential tool for applying marginal analysis in zero-base budgeting is the decision package.

The programs, or functions, or services of an organization are described in terms of these decision packages.

Thus the first step in zero-base budgeting is the identification of the programs, etc. which comprise the budget. The answer to this question for an organization like the Army is to identify the level at which the zero-base budget technique is to be applied. A top-down approach in the Army's case might identify major weapons systems, such as Patriot, as indicative of the level

at which programs should be described in terms of decision packages. Another top-down level for program definition could be the program element. This paper will focus on the bottom-up approach for which the appropriate level of program definition is the sub-task or work unit as described in form 1498, Work Unit Summary, which is widely known and is available for congressional review.

Applying our definitions to this particular case, the second essential step in zero-base budgeting is the preparation of several decision packages for each proposed work unit in the budget. The most important feature of this group of decision packages is that it describes the objectives which can be attained in the work unit during the budget year under consideration FOR DIFFERENT LEVELS OF FUNDING OF THE GIVEN WORK UNIT. This step is essential to zero-base budgeting and provides the information which permits a marginal analysis of the budget to be made. The theory of this approach to budgeting was laid down some time before zero-base budgeting took it over (3).

The third essential element in zero-base budgeting is the prioritization of decision packages according to a scheme which, in our case, identifies and hopefully quantifies the desirable characteristics of the work units which make up the program of the laboratory. The budgetary process then consists of funding the decision packages in their order of priority until the available funds run out.

Some controversy exists over the application of zero-base budgeting at the governmental level which we must briefly address.

ZERO-BASE BUDGETING APPLIED TO GOVERNMENTAL FUNCTIONS

There has been some healthy debunking of ZBB. Robert N. Anthony (of impressive credentials from DoD and Harvard) characterizes ZBB as a fraud because the zero benchmark was replaced by one of the 80 percent level of current spending in the implementation of ZBB in the State of Georgia. In addition, he says, the approach is unmanageable because, in Georgia there were 11,000 decision packages to evaluate and prioritize (a four hour a day job for two months for the governor if he gave a minute to each one, Mr. Anthony calculates!) He proposes sidestepping these problems by renaming the process a "zero-base review" and thus capitalizing on the prestige involved in the new term (4).

However, as Peter Pyhrr says, "Governor Carter concentrated his time on reviewing policy questions, major increases and decreases in existing programs, new programs and capital expenditures and a few packages and rankings where there appeared to be problems." (5).

Thus, whereas all line managers are involved in the zero-base budgeting preparation, the role of top managers will properly be highly selective in its emphasis.

John Hayward, gives ZBB short shrift under the title, Buzz Words Galore. He assumes that ZBB is a review process and argues that the Federal budget is already the result of "continuous reiterations between many agencies, Congress and the Executive." He praises the Budget Reform Act of 1974 and says, "Why add a nonsense called 'zero-base Budgeting' to what will become by sound evolution a sensible process." (6)

Jim Nagle has a related concern - "that ZBB (will travel) down the same ill-fated path as its predecessors - PPB and MBO." (7)

Neither the President nor the Congress are paying much attention to the debunkers. Under Senator Muskie's leadership,bill S.2925 was introduced in the 94th Congress with backing from more than half the Senate. This bill calls for automatic termination of authorizations for a program after 5 years with renewal only after a zero-base review has been made by Congress (8). In the current, 95th Congress, a similar "sunset" bill has been introduced (S.2) with a simplified review process.

The President lost no time in initiating ZBB in his administration. In a memorandum to the heads of executive departments and agencies dated February 14, 1977 he directed the Director of OMB to revise the Federal budget process to incorporate "the appropriate techniques of the zero-base budgeting system" for each department and agency of the Executive Branch for application to the FY-79 budget.

Implementation instructions for submission of agency programs for FY-79 to OMB in September 1977 were issued (9) and reflect the considerable experience of zero-base budgeting which has been accumulated at this time in the private and public sectors.

These instructions, by their balanced viewpoint and emphasis on adapting ZBB to the circumstances and purposes of individual departments and agencies, serve as an effective rebuttal to the type of debunking quoted above.

During this time when the top-down aspect of zero-base budgeting is gathering momentum a number of federal agencies (including the Army, Navy, HEW and EPA) have begun to apply it to parts of their operations(1).

RESOURCE ALLOCATION IN AN R&D LABORATORY (10)

Resource allocation in a Research and Development Laboratory requires that decisions be made about the funding of ongoing and proposed projects. Integral with the funding decisions is the assignment of in-house personnel, and appropriate facilities, supplies and equipment, to the funded projects.

The momentum of ongoing projects is strong and tends to dominate the budget process. The inefficiencies of this procedure in a dynamic environment suggest the application of zero-base budgeting concepts where the total program of the organization is examined, using uniformly-applied, objective criteria, and old projects have to compete with new projects for the available funds.

While major budget decisions are an annual affair enough changes occur to require significant resource allocation decisions to be made from time to time in the course of a typical fiscal year. The same basic issue then arises. Is the organization in a position to rapidly and objectively reassess its allocation of resources to projects and make suitable adjustments to the current program in response to the changed circumstances?

To apply zero-base budgeting concepts it is necessary to have appropriate objective criteria to evaluate ongoing and proposed projects. In addition, it is necessary to decide upon the manner in which this approach to the programming and budgeting tasks is to be implemented. Judgement is necessary. While an inherent subjectivity associated with close and personal attention by management to programming decisions is both inevitable and desirable, the application of objective optimizing techniques to the initial preparation of the program (and resultant budget) introduces important flexibility into the budgeting process. The effects of contingencies which change the budget level and the relative priorities of the projects can be readily ascertained through simulation exercises (what if we were faced with a 20% program decrement?) and adjustments to the program in the course of the fiscal year can be made within the context of an optimization of the benefit of the total program.

APPLICATION OF ZERO-BASE BUDGETING TO R&D (10)

As described above, zero-base budgeting is the process of allocating the funds of an organization to a number of "decision packages" according to their ranking in priority order. A given project will consist of a number of these "decision packages" each of which will describe an incremental part of the project.*

Thus let us suppose that there are three projects (1, 2 and 3) and that each one is described by program increments A, B, C etc. Then the basic program or decision package for project 1 is package 1A; for project 2, package 2A, etc. The "A" packages describe the highest priority work in each project, the "B" packages the next most important work objectives and so on. Another way of looking

*Alternatively decision packages may describe increasing expensive budgets for a given project with greater progress associated with greater cost. This latter approach is described in the guidelines published by OMB (9).

at the "A" packages is to view them as the smallest, viable program which can be conducted on the given project. In other words, the "A" packages define the minimum program which is worth doing on the project. These two concepts of the "A" package are logically related to each other by the assumption that the minimum program will be focussed on the highest priority objective.

The first essential concept, then, in the adaptation of the zero-base budget approach to R&D is the description of multiple, optional funding levels for each project in a given year. Another desirable feature of zero-base project planning is the definition of alternative funding approaches for each decision package. Without multiple funding levels the only possible funding decision about a project is yes or no, which is too crude a decision measure. The addition of alternative funding approaches (affecting the "mix" of in-house and contractual effort) provides the flexibility to simultaneously optimize the funding of projects according to their priority and the utilization of the work force according to their unique profile of skills.

The second fundamental step is the prioritization of decision packages. Objective criteria of merit must be developed which must be uniformly applied to all the decision packages. This means not only the ranking of projects with respect to each other, but also the ranking of project increments across project boundaries. For example, the packages referred to in relation to projects 1, 2, and 3 on the previous page might emerge from the ranking process in the following order: 1A, 3A, 3B, 2A, 2B, 1B, 1C, 3C, 2C. Notice that package 1A precedes package 1B which, in turn, precedes package 1C, and similarly for project 2 and project 3. However, in this example the second increment of project 3 (3B) rates higher than the first increment of project 2 (2A). It is not difficult to imagine situations in which this type of ordering could come about.

In summary, the major steps in implementing a zero-base approach to budgeting are:

*identify the projects which are candidates for the funds

*determine alternative funding levels for each project

*prepare decision packages to cover the minimum funding level and each increment in funding for each project

*define criteria of merit for evaluating the decision packages

prioritize decision packages at the first level of management

*prioritize decision packages at the laboratory level of management

*that is, the level of management which is responsible for a number of projects (or work units)

THE FAMILY OF SYSTEMS STUDY AND ITS ROLE IN

*compile the laboratory program and budget as a function of various contingency levels of funding

At this point the results of the process will be critically reviewed by management. A number of changes will be made as a result of management judgment and experience and the budget will be reworked. In this way ZBB is used as an aid to planning, programming and budgeting and not at all a process which dictates what the budget will be.

Relationship Between Decision Packages, Work Units and Projects.

Projects. A project is a complete piece of work which results in the development of a piece of hardware, the development of a new technique or the accomplishment of a major research goal. Projects are invariably multi-year efforts, frequently encompassing one or more transitions in funding, e.g. from 6.1 research to 6.2 exploratory development, or from 6.2 exploratory development to 6.3 advanced development (e.g. the crosswind sensor).

Projects and Decision Packages. In general the plan for accomplishing a project will include several objectives each year. The minimum level of effort for maintaining progress on the project in a given year will be described by a decision package. One or more additional decision packages will describe increments of work which would expedite the project.

Work Units. The work unit is the description of the funded work on a project within each funding category (e.g. 6.1). Thus the plan for completing a project may involve a work unit in the 6.1 funding category lasting say, three years, followed by a work unit in the 6.2 funding category lasting another two years. In any given year the funding level may correspond to say two decision packages comprising the minimum objectives plus additional objectives which are evaluated as having high enough priority to be funded within the budget of the laboratory.

The Decision Package and Project Funding

Each decision package contains:

*a statement of the requirement for the work (impact of not doing the work)

*a definition of the problem from the user's point of view (the military problem being faced)

*a definition of the problem from the scientist's (or engineer's) point of view (the technical barriers to be overcome to solve the military problem)

*the goal of the work and the projected year of completion

*the approach used

*past achievements and current status and current year milestones (for ongoing work)

*objectives for the budget year

*significant milestones in terms of the user's requirements and timetable and

*the budget for the work preferably showing two options in the way the work is funded.

At the planning stage, a project consists of at least one funded decision package each year from project inception to project completion. This is the core program for the project. Alternatively the project may be completed in less time by funding incremental decision packages in addition to the core program in any given year. The project plan will identify major milestones each year but the planning detail necessary to write decision packages will be developed only as far as the budget year under consideration.

FACTORS INVOLVED IN EVALUATING AND PRIORITIZING DECISION PACKAGES (10)

Development of criteria of merit. In order to evaluate and rank the decision packages it is necessary to develop criteria of merit which will be generally applicable within the laboratory. Qualitatively the merit of a project might be described in terms of answers to such questions as: (application is made here to the authors' laboratory)

*what science and technology objectives does this project relate to?

*how relevant is it to these objectives?

*does the work feed in to a larger program (for example,does it provide a component part of a major weapon system)

*what priority does the project have relative to Army needs?

*what effect do higher level decisions, policy, and guidance have on project determination?

The difficulties arise when an attempt is made to quantify these types of criteria.

Measures of performance for ongoing work. If the work is ongoing, further questions may be asked:

*how well has the work progressed?

*what contributions have already been made to the solution of Army problems?

*in what way has the work contributed to the advance of the atmospheric sciences?

In these cases also it is necessary to reduce these issues to quantitative terms in order to be able to rank the projects.

Levels of prioritization. Decision packages may be prioritized at each organizational level in the laboratory. However, at a minimum, prioritization should be carried out at the first management level and at the laboratory level. The first managment level prioritization is necessary to obtain the expert judgement of those who are intimately involved with the work. The laboratory level prioritization is necessary in order to construct the laboratory budget.

Subjectivity in prioritization. Undoubtedly the problem of giving relative weightings to unlike projects in particularly acute at the laboratory level and the subjective element of judgement is unavoidable. However, progress will be made if the factors which should enter into the weighting process are explicitly described. It is also important that the application of subjective judgement be made in a consistent manner and be accompanied by a stated rationale. To some extent the techniques used to judge the responses to a request for proposals (RFP) offer a guide as to what might be done.

A MODEL FOR PROJECT EVALUATION (10)

The objective of the budgeting process is to maximize the benefit of the funded work. In order to do this projects must be ranked according to established criteria which will provide a figure of merit for each project. How can such a figure of merit be derived?

Clearly, the priority of the work in the eyes of the customer is a relevant consideration. Within this category two factors can be identified: the inherent importance of this piece of work to the customer and the urgency with which it should be pursued. Especially if the piece of work is part of a larger system,delay may impact adversely on the system as a whole or alternatively the piece of work may be postponed for a year even though it is a necessary part of the system.

Independent of the importance and urgency of work is its feasibility. What is the probability of it being successfully completed within the time frame contemplated? This depends upon an assessment of the technical barriers involved and of the skill of the scientists available to work on the problem.

To minimize the occurrence of unreasonable behavior in a model, particularly when parameters take on the values associated with the limits of the range within which they vary, it has been found that quantities are best represented by factors multiplied together in a geometrical form rather than added or subtracted in arithmetical fashion. This procedure is commonly used in the various applications that have been made of systems dynamics such as industrial dynamics, dynamics of commodity production cycles and urban dynamics.

It is important that the factors which comprise a given quantity be substantially orthogonal to one another. That is to say they should represent independent properties of the quantity being described. The factors germane to the figure of merit of an R&D project which have been identified at the beginning of this section can be seen to meet this criterion. To the extent that orthogonality does not obtain the model of the quantity of interest will distort its behavior as the factors change in value.

These principles underlie the construction of "robust" models and will be used in the following treatment.

The figure of merit for each work unit is defined to be the product of the priority factor and the probability of successfully completing the work. The priority factor becomes a function of both the stated requirement for the work effort and the impact of possibly delaying this effort. Numerical values may then be assigned to each of these factors.

PRIORITIZING WORK UNITS IN THE FY-78 BUDGET

During the Spring 1977, a committee at the Atmospheric Sciences Laboratory was requested to review projected work units for FY-78 and establish priorities based on documented user requirements.

The committee utilized the procedures as described above and ranked the FY-78 work units according to numerical scores by rating each of the factors independently.

The rating of each work unit was accomplished by using each member of the committee as an expert judge to assign a score for the requirement and the urgency of the work unit. These scores were then discussed and reasons for extreme scores compared to the average were explained by the raters involved. The work was then rescored with each judge (rater) having the opportunity to change his score. If extreme values still occurred, they were discarded in calculating the average score.

This modified Delphi technique coupled with the model was judged to be a satisfactory approach to the assigned task of prioritizing work units according to as objective techniques as possible. (11)

The resulting priority list was used as one input (among several) by laboratory management in deciding which work units should be funded in FY-78.

This step towards a more objective solution to the resource allocation problem can be improved so far as optimizing the benefits of the laboratory program is concerned. The fact that work units were either funded or unfunded is unnecessarily severe a judgment. Could some additional work units have been funded by giving other work units less than the (one) funding level requested, with a resulting increase in the net benefit of the program to the laboratory? The addition of other funding levels for the work units would have enabled this type of question to have been systematically pursued.

Of course, at this point, the concepts of zero-base budgeting as described above would have been applied, and one could conclude that an optimization of the laboratory program requires the utilization of all the essential elements of zero-base budgeting.

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ABSTRACT

TITLE: ESTIMATED COST OF REPAIR PARTS FOR THE M240 MACHINE GUN STATEMENT OF QUALITY AND SUPPORT (SOQAS), WARRANTY PERIOD

AUTHOR(S): Mr. Norman H. Trier and CPT Larry W. Krueger

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ABSTRACT: The cost of repair parts during SOQAS (warranty) periods of 30, 45, and 60 days was estimated for 10,000 M240 Machine Guns. The expected number of required repair parts during a warranty period was estimated by predicting the number of expected failures based on the final OT III data and the expected usage rate during the warranty period. For the purpose of estimation, a normal distribution was found (through graphical techniques) to apply to the OT III parts replacement data. Then, the expected number of failures was calculated by multiplying the probability of failure by the appropriate weapon density. Finally, the cost of parts replacement was calculated for warranty periods of varying lengths of time.

ESTIMATED TIME REQUIRED FOR PRESENTATION: 30 Minutes

CATEGORY APPROPRIATE FOR THIS PAPER: Special Session Topic: Resource Analysis

TITLE: ESTIMATED COST OF REPAIR PARTS FOR THE M240 MACHINE GUN STATEMENT OF QUALITY AND SUPPORT (SOQAS), WARRANTY PERIOD

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OBJECTIVE

To analyze parts replacement data and expected costs for the purchase of repair parts for 10,000 fielded M240 Machine Guns during a 30 to 60 day Statement of Quality and Support (SOQAS) warranty period.

INTRODUCTION

The M240 Armor Machine Gun and mount will replace the present coaxial machine gun and mount. From the date of installation, the Army Materiel Development and Readiness Command (DARCOM) will warrant the M240 Machine Gun System for a specified period of time. That is, DARCOM will replace any Basic Issue Item (BII) or repair part during the warranty period except those items which are lost or show definite signs of abuse or mishandling.

The Maintenance Directorate, DRSAR-MA, will request a Statement of Quality and Support (SOQAS) commitment to the user from HQ, DARCOM in accordance with the provisions contained in DARCOM Supplement 1 to AR 700-127. As a basis for planning and programming, an estimate of the cost of repair parts during a warranty period was requested. In response to DRSAR-MA's request, the cost of repair parts required during a specified warranty period was estimated by analyzing the data compiled during the Operational Test III (OT III). All costs in this analysis are those recommended by the developer, Fabrique Nationale.

METHODOLOGY

The expected number of required repair parts during a warranty period was estimated by predicting the number of expected part failures based on the final OT III data and the expected usage rate during the warranty period. For the purpose of estimation, a normal distribution was found (through graphical techniques) to apply to the OT III parts replacement data. The probability that a failure will occur before a specified number of rounds are fired from a weapon was calculated as follows:

$$K_\alpha = (b - \hat{\mu})/\hat{\sigma} \rightarrow P\ (\text{failure} \leq b \text{ rounds}) = \alpha$$

where

K_α = the normal deviate corresponding to α

α = probability of a failure

$\hat{\mu}$ = the mean of the data points

$\hat{\sigma}$ = standard deviation

b = number of rounds fired to obtain the probability α

Once K_α is calculated, α is obtained from tables for the normal distribution. Then, the expected number of failures is calculated by multiplying the probability of failure, α, by the number of weapons considered.

It was estimated that the average number of training rounds fired on a coaxial machine gun is five to seven thousand rounds per weapon per year[1]. At this point a decision was made whether to:

a. Assume that a monthly average of rounds are fired from the weapons; i.e., if 7,000 rounds are fired on a weapon during the first year, then 583 rounds are fired each month. With this monthly firing rate, the number of failures are computed each month.

b. Assume that a monthly average of failures occur during the first year. With this uniform failure rate, failures are computed for the first year and then averaged over the months.

It was decided to use the latter assumption, since, for budgetary reasons, funds need to be set aside to cover the actual cost of parts replacement during the warranty. The actual number of rounds fired on weapons during the warranty period will depend on such things as the availability of firing ranges, the availability of rounds, and the training requirements for the troops.

Along with the above method, a parametric analysis was used to predict the expected number of failures in order to show how the number of failures varies with the distribution of rounds fired on the weapons. The four cases, shown in Table 1, vary in the number of weapons firing specified numbers of rounds while maintaining an overall average of 7,000 rounds fired per weapon. Case 1 is the baseline case where the number of predicted failures is at a minimum. Cases 2, 3, and 4 are possible representative distributions of actual field usage.

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[1]TRADOC, Fort Knox, KY, message R241704Z Oct 75.

TABLE 1. Cases Addressed for Parametric Analysis

Case 1:	10,000 weapons fire an average of 7,000 rounds per year
Case 2:	3,000 weapons fire an average of 3,500 rounds per year
	4,000 weapons fire an average of 7,000 rounds per year
	3,000 weapons fire an average of 10,500 rounds per year
TOTAL:	10,000 weapons fire an average of 7,000 rounds per year
Case 3:	3,500 weapons fire an average of 3,000 rounds per year
	4,500 weapons fire an average of 7,000 rounds per year
	2,000 weapons fire an average of 14,000 rounds per year
TOTAL:	10,000 weapons fire an average of 7,000 rounds per year
Case 4:	4,500 weapons fire an average of 3,000 rounds per year
	3,000 weapons fire an average of 7,000 rounds per year
	1,000 weapons fire an average of 11,000 rounds per year
	500 weapons fire an average of 21,000 rounds per year
TOTAL:	10,000 weapons fire an average of 7,000 rounds per year

DISCUSSION OF DATA

During OT III, in which an average of 69,638 rounds were fired from each of the five M240 Machine Guns, 59 parts had no failure, 14 parts had only one failure, and 11 parts had more than one failure. Furthermore, during the first 10,000 rounds fired from each weapon, no failures occurred (several rounds fired from each of the five machine guns, only 14 parts failed, eight had only one failure, and six had two or more failures.

Of the 11 parts which had two or more failures during the entire OT III test, only five of the parts had unit costs greater than $1.00 each. Therefore, the expected number of failures during the first year of fielding were calculated for the following five parts only: Charging Cable; Charging Slide; Feed Tray; Spring Assembly Return (also called the Spring, Return Charger); and Roller, Feed Channel. Table 2 displays those five repair parts, their unit prices, the number of data points, and the mean and standard deviation of the number of rounds fired before a failure occurred.

TABLE 2. Data for Selected Parts of the M240 Machine Gun

DESCRIPTION	UNIT PRICE	NO. OF FAILURES	MEAN (K RDS)	STANDARD DEVIATION (K RDS)
Cable, Charger	$ 8.50	4	38.26	12.30
Slide, Charger	$ 10.75	4	41.12	23.03
Tray, Feed Assy	$109.00	17	17.91	5.94
Spring, Return Charger	$ 2.25	11	25.80	9.24
Roller, Feed Channel	$ 25.00	4	44.16	28.50

RESULTS

Using the methodology as described with the five parts identified above, failures were predicted for the first year and are summarized in Table 3.

TABLE 3. Summary of Predicted Failures for First Year

	NUMBER OF FAILURES			
PART DESCRIPTION	CASE 1	CASE 2	CASE 3	CASE 4
Cable, Charger	45	55	71	95
Slide, Charger	327	337	353	369
Tray, Feed Assembly	315	458	664	840
Spring, Return Charger	242	289	355	433
Roller, Feed Channel	362	367	381	393

The total expected annual costs can now be calculated by totaling the product of the expected number of part failures and their respective unit prices. As is shown in Table 4, the expected cost of supporting 10,000 weapons for the first year is calculated to be from \$47.8K to \$107.1K (a monthly average of \$4.0K to \$8.9K, respectively).

COST OF WARRANTY FOR PARTS REPLACEMENT

The cost of parts replacement for warranty periods of varying lengths of time can be computed by taking a weighted average of the annual cost of parts replacement. The predicted costs of parts replacement are displayed in Table 4 for each case for warranty periods of 30, 45, and 60 days. For example, the predicted cost of parts replacement for a 45 day warranty period for Case 2 is \$8.0K.

TABLE 4. Predicted Cost of Parts Replacement for Warranty Of 10,000 Machine Guns[a]

Warranty Period	Case 1[b]	Case 2[c]	Case 3[d]	Case 4[e]
30 Days	\$4.0K	\$ 5.3K	\$ 7.3K	\$ 8.9K
45 Days	\$6.0K	\$ 8.0K	\$10.9K	\$13.4K
60 Days	\$8.0K	\$10.6K	\$14.5K	\$17.9K

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[a]based on OT III data.

[b]each of the 10K weapons fired average of 7K rds.

[c]3K weapons fired 3.5K rds, 4K weapons fired 7K rds, and 3K weapons fired 10.5K rds--a total overall average of 7K rds.

[d]3.5K weapons fired 3K rds, 4.5K weapons fired 7K rds, and 2K weapons fired 14K rds--a total overall of 7K rds.

[e]4.5K weapons fired 3K rds, 3K weapons fired 7K rds, 1K weapons fired 11K rds, 1K weapons fired 14K rds, and 0.5K weapons fired 21K rds--a total overall average of 7K rds.

TABLE 4. COST OF PARTS REPLACEMENT FOR THE FIRST YEAR FOR 10,000 M240 MACHINE GUNS

PART DESCRIPTION	UNIT COST	CASE 1		CASE 2		CASE 3		CASE 4	
		No. of Failures	Total Cost	No. of Failures	Total Cost	No. of Failures	Total Cost	No. of Failures	Total Cost
Cable, Charger	$ 8.50	45	$ 382.50	55	$ 467.50	71	$ 603.50	95	$ 807.50
Slide, Charger	$ 10.75	327	$ 3,515.25	337	$ 3,622.75	353	$ 3,794.75	369	$ 3,966.75
Tray, Feed Assembly	$109.00	315	$34,335.00	458	$49,922.00	664	$72,376.00	840	$ 91,560.00
Spring, Return Charger	$ 2.25	242	$ 544.50	289	$ 605.25	355	$ 798.75	433	$ 974.25
Roller, Feed Channel	$ 25.00	362	$ 9,050.00	367	$ 9,175.00	381	$ 9,525.00	393	$ 9,825.00
TOTAL FIRST YEAR COST			$47,827.25		$63,837.50		$87,098.00		$107,133.50
MONTHLY AVERAGE			$ 3,985.60		$ 5,319.79		$ 7,258.17		$ 8,927.79

SUMMARY

The total first year cost of repair parts was estimated to be $48K to $107K. Therefore, the warranty cost for repair parts are:

Warranty Period	Cost of Parts Replacement: Total for 10,000 Weapons	Per Weapon Cost
30 Days	$4.0 to $ 8.9K	$0.40 to $0.89
45 Days	$6.0 to $13.4K	$0.60 to $1.34
60 Days	$8.0 to $17.9K	$0.80 to $1.79

These estimates are based on OT III parts replacement data and suggested unit prices by the developer, Fabrique Nationale. By assuming that a uniform distribution of failures occurs over the first year, a higher number of failures would be predicted as opposed to assuming a uniform usage rate of rounds over the first year. The uniform distribution of failures was used so that sufficient funds would be set aside to cover the cost of parts replacement during the warranty period. The actual number of failures will, of course, depend on such things as the availability of firing ranges, availability of rounds, and the training requirement for the troops.

THE FAMILY OF SYSTEMS STUDY AND ITS ROLE IN ARMY SYSTEMS ANALYSIS.

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ABSTRACT

This paper presents the concept of a "Family of Systems Study" (FOSS) and explains the role that it can play in the analysis of Army systems in general. Several aspects of the FOSS are examined. First, the underlying motivation for the FOSS is given. This serves to put the FOSS in its proper historical perspective and also serves to show why the conduct of a FOSS is an essential part of total systems analysis. Second, a top level description of an analytical approach for conducting a FOSS is presented. This includes a description of the FOSS methodology itself as well as the identification of requisite inputs and background work for the study. Third, a brief discussion given on the organizational (though task oriented) responsibilities necessary to conduct a FOSS. Within the TRADOC community, this serves to establish bounds for the expenditure of both time and manpower resources on the FOSS effort. Fourth, a broad perspective is given of what is foreseen as the major contributions of a FOSS. This serves to identify the function of the FOSS in relation to overall Army systems analysis programs. Finally, by way of illustration, two examples are given of specific implementations of the FOSS analysis process to families of systems.

INTRODUCTION

A Family of Systems Study (FOSS) is an analysis which addresses problems of broad scope and which spans several functional areas associated with a collection of systems. It is a vehicle for validating systems' requirements in a "total" environment and for identifying systems' operational performance gaps or overlaps given a functional requirement. It seeks to examine the collective capability of systems rather than the capability of individual members of the family. Fundamentally, it is an analysis of systems in complementation rather than an analysis of systems in isolation. It provides for variable levels of analysis (ranging from small combat units to large combat forces) and examines critical issues bearing on an entire family of systems. More precisely, a FOSS is an analysis of families of combat systems aimed at resolving issues which arise from (1) the Materiel Acquisition Process (MAP) of each system in a family and (2) the interrelationship of the MAPs of systems belonging to the family.

THE FOSS CONCEPT

Background

The FOSS is not a new concept in the analysis of Army weapon systems. It has been implemented in diverse guises by a number of agencies for a variety of purposes. Examples include the ARCSA studies (Aviation), the LEGAL MIX studies (Artillery) and the AIR DEFENSE studies to name but three. In some instances the FOSS has been institutionalized and is conducted systematically. In other instances, it is directed and conducted on an "ad hoc" basis. In either case, however, it serves the same purpose; namely, to provide a comprehensive analysis base from which to make decisions concerning Army weapons systems development. The FOSS, in its various forms, has been one way for top level decision makers to reduce the risks and uncertainties inherent to making large numbers of essentially piecemeal decisions. It has provided the superstructure for decision processes that are otherwise driven mainly by considerations of budget and programming cycles.

Therefore, to the extent that there has always been a need for comprehensive analyses which provide an understanding of the mid and long range implications of individual decisions and which also allows decision makers to assess the cumulative impact of these decisions, FOSS is, in fact, a very old concept.

Analysis Needs

Specific needs can be identified which motivate the requirements for a specific FOSS. They are: (1) the need (especially at high Army decision levels) to respond to issues which concern very broad

functional areas and which affect a wide range of related Army systems,
(2) the need (at intermediate to high levels) to address issues which impact entire families of related systems from a common and comprehensive decision base, and
(3) the need (at lower, supportive levels) to enhance the responsiveness to requests for analysis support which can aid in the resolution of critical systems issues.

FOSS responds to the first of these needs in that it provides to top level decision makers information on which to base systems "trade-off" decisions. These decisions usually involve selecting between systems that are equally good (in some sense) but which are competing for the same limited resources. The FOSS can help make this selection. It can, in most cases, assist in the process of deciding among systems that are effective in their own right, but must be weighed, one against the other, so that "on balance" the system providing the greatest benefit is selected. For these executive decisions, factors involving more than just product quality or effectiveness must be considered. Programming or budgetary constraints must often be brought to bear on the decision. Subjective elements enter into the decision, of course, and to the extent that they do, no analysis will ever wholly satisfy this need. However, FOSS, with its emphasis on the examination of families of systems which are related both functionally and characteristically and which perform a spectrum of combat and combat support functions, can provide insight into the implications of these decisions.

The FOSS can serve the second need in that in can adequately address the issues which deal with whether a system requirement actually exists. This exercise normally takes the form of "validating" a stated requirement and can best be done by performing system operational analyses in given combat scenarios. FOSS can address these issues analytically within the framework of a family study and can therefore play a significant role at this decision level.

FOSS can also satisfy the third need by providing a sound base from which to do more detailed systems analyses. Several ways in which the FOSS can help here are the following. First, it can decrease study "start-up" time for doing follow-on analysis. General analysis procedures will have been defined by the FOSS and minimal study planning should therefore be required. Second, it can lay the preliminary groundwork for subsequent analyses by doing the initial screening of alternatives. Alternatives which are clearly not feasible can thus be eliminated very early in the study effort. Third, FOSS can lessen the agonizing (and usually schedule-shattering) task of data collection. The development of system data bases as part of the FOSS can potentially save up to 50% of normal study time. Fourth, the FOSS can provide continuous and consistent analyses of systems throughout their entire acquisition cycle. It can, in this way, make studies comparable even when they are performed at different points in the MAP. More importantly though, it can allow studies to be expanded and built upon. Currently, this cannot readily be done. The present system of COEA "updating", in practice, reduces to COEA "re-doing". Valuable knowledge and experience gained in one study iteration is seldom passed on the the next iteration. Finally, FOSS can provide the necessary analysis tools (methodologies, models, algorithms, data bases, etc.) which will get the study underway quickly. It can, in this manner, reduce the early steps in starting studies which call for (1) the definition of analysis mehtodologies, (2) a search for "the model" to apply to the studies, and (3) the identification and accumulation of data required by the studies.

Family Partitions

In seeking to do comprehensive studies of Army weapon systems, analytical tractability is a principal concern. One way of achieving it is by inducing a partition on the set of systems to be studied and then analyzing the parts separately. Results for the total set can then be obtained from the separate analyses by accounting for the complementary aspects of otherwise individual investigations.

Partitioning of the set of weapon systems can be done along two dimensions: (1) function and (2) characteristics (either engineering or operational). Once partitioned, the systems can be examined by grouping them along one dimension and analyzing them along the other. In the concept of the FOSS as expounded in this paper, the grouping of systems is done by characteristics and the analysis is done according to battlefield functions. This approach is particularly tractable because it is consistent with the prevailing organizational structure of the Army and with the established methods (procedural and administrative) for conducting studies within the Department of the Army.

In this approach, the "families" consist of systems having similar characteristics. One list of families (and certainly not unique) resulting from this approach to the FOSS is shown in Table 1. For completeness, the table also shows the established proponency, within TRADOC, for these families.

TABLE 1	
FAMILY OF SYSTEMS PARTITIONS	
FAMILY	PROPONENT
AIR DEFENSE	US ARMY AIR DEFENSE SCHOOL
ANTI-ARMOR	US ARMY COMBINED ARMS CENTER
ARMOR (COMBAT VEHICLES)	US ARMY ARMOR CENTER
ARTILLERY	US ARMY FIELD ARTILLERY CENTER
AVIATION	US ARMY AVIATION CENTER
BATTLEFIELD LOGISTICS AND REPAIR	US ARMY LOGISTICS CENTER
COMMAND AND CONTROL AND ADP	US ARMY COMBINED ARMS CENTER
COMMUNICATIONS AND EW	US ARMY SIGNAL CENTER
ENGINEER	US ARMY ENGINEER CENTER
INFANTRY	US ARMY INFANTRY CENTER
INTELLIGENCE	US ARMY INTELLIGENCE CENTER
NBC DEFENSE	US ARMY ORDNANCE CENTER

The analysis of the families is carried out by determining how well each family can perform its battle functions. This is a two-step operation. First, battle function requirements are established for each family. This is done by specifying and cataloging the tasks that each family must execute in its role as part of the Combined Arms Team. The various "How to Fight" manuals are used as the basis for this process. Second, analysis-level requirements are established for each family. The Operations Manual, FM 100-5, is used for this purpose since it connects and is the basis for all other manuals. According to this manual, battle functions are classed into three general catagories: (1) Concentration of Forces, (2) Management and Direction of Battle, and (3) Conduct of Battle. This function breakout induces a corresponding catagorization of the analysis-level requirements. This is shown in Table 2. The analysis level required by the FOSS can then be established consistent with the function requirement as determined by the family.

TABLE 2	
FOSS REQUIREMENT CORRELATION	
FUNCTION CATEGORY	ANALYSIS LEVEL
CONCENTRATION OF FORCES	DIVISION AND HIGHER
DIR/MGMT OF BATTLE	BATTALION
CONDUCT OF BATTLE	COMPANY AND BELOW

FOSS Emphasis

The emphasis in a FOSS is different from the emphasis in studies of more limited scope. Typically, Army

systems studies are directed toward examining specific items of equipment performing specific tasks. For these studies materiel need requirements are first established and investigations are then carried out to determine the operational effectiveness of the equipment. By contrast, a FOSS examines a family of related systems performing a broad spectrum of functions. For example, in the Engineer FOSS the family of Engineer equipment is examined with respect to the diversity of combat support functions it performs as part of the Combined Arms Team. While Engineer equipment is not (normally) involved in "contact" operations, it nevertheless contributes to the total battle. The Engineer FOSS quantifies this contribution.

There are other differences in emphasis between a FOSS and other studies of Army systems such as Cost and Operational Effectiveness Analysis (COEA). The following list points out a few of these differences.

(1) In a FOSS, the operational concept for a family of systems executing its associated functions is a subject for analysis. In a COEA, the operational concept for the equipment under study is specified and remains fixed throughout the study.

(2) In a FOSS, the analysis is done relative to a spectrum of combat scenarios. In a COEA, a scenario is defined and forms the basis for the study.

(3) In a FOSS, variable force structures are analyzed for their effectiveness. While in a COEA, fixed force structures, as defined by Tables of Organization and Equipment, are assumed.

(4) Finally, in a FOSS, high fidelity in the analysis parameters is not a prerequisite to the study. In a COEA, on the other hand, high fidelity of parameters is essential in order to properly discriminate among competing systems.

Other distinctions between FOSS and COEA could be drawn. However, the ones listed here serve to illustrate the fundamental difference in emphasis between the two types of studies.

THE FOSS PROCESS

The FOSS process consists of two major parts: (1) the identification of the components making up the process and (2) the development of an analysis methodology which permits the implementation of the process. The first part determines the generic structure and procedure of a FOSS while the second establishes the specific mechanics by which the FOSS can be executed. Both parts are pivotal, although complementary, in the total FOSS process.

FOSS Components

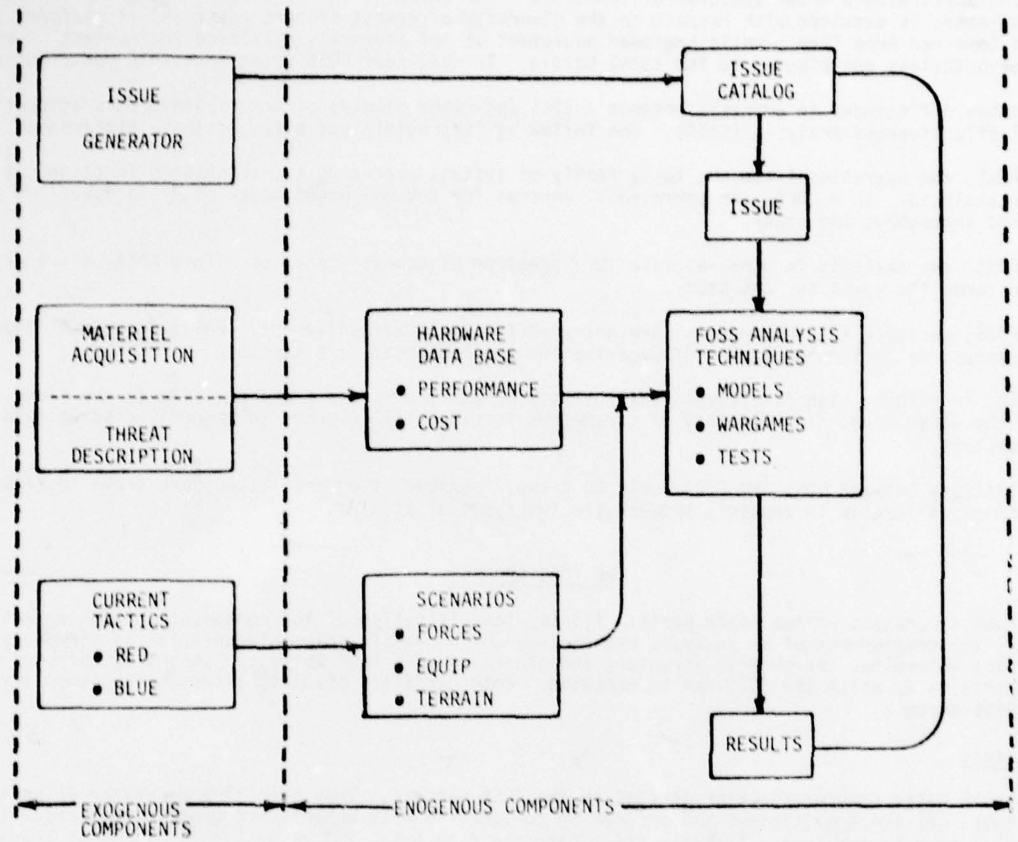
There are seven basic components which constitute the FOSS process. They are (1) a generator of critical systems issues, (2) the Army systems MAP program in conjunction with established enemy threat capabilities, (3) the combat systems employment tactics, (4) a hardware data base, (5) an inventory of combat scenarios, (6) a catalog of critical systems issues, and (7) a repertoire of systems analysis techniques.

These components fall into two basic groups. One group (consisting of the first three items listed above) includes those components that are exogenous to the FOSS itself. This group is characterized by the fact that its members are self actuators". Differently said, this means that the processes intrinsic to the components in this group in no way depend on whether a FOSS is planned, developed or executed. Indeed, these components evolve independently of the FOSS and are essentially the "uncontrollables" of the FOSS process.

The second group consists of components that are endogenous to the FOSS. It includes the last four entries of the list given above. This group is characterized by the fact that the evolution of the components contained in it is completely determined by the FOSS. In this sense, the components in this group are wholly within the control of the FOSS analyst.

The interrelationship between the FOSS components is not difficult to see. It is depicted graphically in Figure 1. Given an issue, an evaluation is made to determine its status. More specifically, the issue is researched to answer such questions as (1) Has it been raised before?, (2) If yes, under what circumstances was it previously raised?, (3) What was done to respond to it?, and (4) Is it still a valid issud? If after this evaluation the issue still warrants further investigation, a determination is made of appropriate analysis techniques which can best aid in responding to it. Once the analysis techniques are identified, the required input data is retrieved from existent data bases and the analysis itself is conducted. The results of this exercise are provided to Army decision makers and at the same time stored in an issues catalog for future reference and evaluation.

Figure 1. FOSS Components

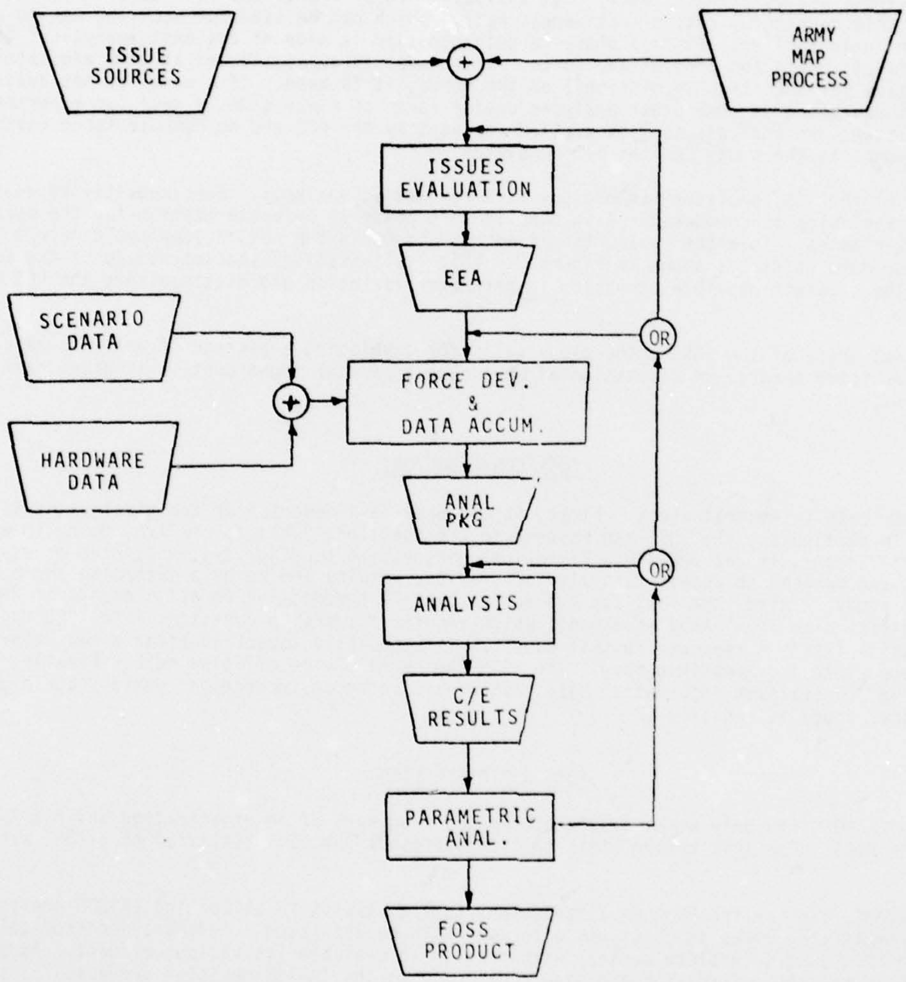


FOSS Methodology

The second major part of the FOSS process is an analysis methodology. Figure 2 shows a generic "TOP LEVEL" FOSS methodology. It shows the methodology as having five distinct phases. Phase I is a Critical Issues Evaluation. Here an assessment is made of the study issues; and the FOSS objectives and Essential Elements of Analysis (EEA) are formulated. Also made here is the determination of the analysis-level requirement which dictates the specific course of the FOSS. The issues for this phase come from a number of sources (schools, centers, developers, users, etc.) and frequently take the form of Required Operational Capability (ROC) papers, Concept Papers, Test Requirement, and other requirement statements. The evaluation of issues also requires that the total Army MAP program be monitored to check whether other systems are being affected. If they are, these issues must also be accomodated. The EEA developed in this phase serve as inputs to FOSS phase II.

FIGURE 2

GENERIC FOSS METHODOLOGY



Phase II of the FOSS methodology calls for the development of force structures and for the accumulation of study data. Forces are defined in terms of quantity and type of equipment and in terms of the organizational configuration of its resources (both men and materiel). Mission and function is of course an important factor in this definition. The study data base is compiled using scenario data, force organizational data, and hardware performance and cost data. It is the central store of information for the FOSS. For greater ability, the data base is further divided into three categories of data: (1) data on current inventory equipment, (2) data on developmental or conceptual systems and (3) data on resource requirements (either manpower, materiel, or time). Phase II produces an "analysis package" consisting of data descriptors for a force, its organization, its equipment, its capabilities, and its set of required tasks. This analysis package is used in FOSS Phase III.

Phase III is the analytical machinery of the FOSS. It is basically a Cost-Effectiveness Analysis of the Family of systems, which is the object of the study. It sets up techniques for performing, separately, a family effectiveness analysis and a family cost analysis. It also provides for integrating the results of these efforts into meaningful cost-effectiveness ratios which can be used for decision making an any of the levels mentioned earlier. In this phase, a determination is made of the best analytical techniques to compute the effectiveness and cost of the force. If a model is available and it will adequately simulate the activities (as specified by missions) of the force, it is used. If a model is not avaialable, then either it is developed or some other analysis device (such as a war game, a test, an experiment, etc.) is used. In any event, an analysis tool is applied to quantify the MOE and to compute force costs so that a meaningful response to the study EEA can be formulated.

The fourth phase of the FOSS analysis methodology is a parametric analysis. Here sensitivity analysis of significant FOSS variables is conducted. Also done in this phase is parameterization for the purpose of optimizing FOSS variables. In either case, the "feedback" loops in the methodology cycle back into the analysis at one or more points as shown in Figure 2. This "self-feeding" characteristic of the FOSS methodology permits the greatest possible excursion in parameter variation and distinguishes the FOSS from more traditional COEA.

The fifth and final phase of the FOSS methodology calls for developing a package of analysis results in a form usuable by decision makers. A discussion of what such a package might contain is given next under FOSS contributions.

FOSS CONTRIBUTIONS

The FOSS can contribute in several areas. First, it can provide a description and giveinsight to current Army programs. In particular, the FOSS can respond to the question, "What is the Army doing in a given functional area?" Second, it can provide a historical perspective to major system studies or staff actions Specifically, it can be used to assess the value of previous results and to help determine the present need for further study. Third, the FOSS can provide an overall perspective on all elements of Army programs. It can assist high level Army assesments which require answers to questions like, "Do the pieces of the program still fit?" A response to this question is especially important after a new major system has been introduced into the Army inventory. The FOSS can certainly be of value here. Finally, the FOSS, with its extensive, centralized information base, can provide program improvement options and highlight areas where further study is required.

FOSS ADMINISTRATION

Administration of a FOSS can only be discussed within the framework of an organization which acts as "sponsor" for the FOSS. For this reason, this section addresses the administration of a FOSS within TRADOC.

Headquarters, TRADOC, can use the FOSS as a management tool to assist in allocating TRADOC analysis resources and in identifying areas in which new efforts should be initiated. Further, a periodically updated FOSS can give to TRADOC HQ a complete context within which to evaluate its various efforts. As such, the FOSS can provide up-to-date information and give continuity to the TRADOC decision process.

TRADOC schools and centers can also benefit from the FOSS. They can obtain an analysis vehicle by which they can validate materiel requirements, analyze tactics, and develop doctrine. It will also provide them with the ability to evaluate all organizational aspects of systems of equipment.

TRASANA can expect to have a more efficient analysis capability as a result of the FOSS. Specifically, COEA will require less manpower and time. The data collection burden will likewise be considerable reduced. Finally, the experience and knowledge gained from FOSS should allow TRASANA to give its customers a better quality product.

FOSS EXAMPLES

In this section two examples are given to show how the generic FOSS methodology gets "personalized" in an application to a particular family.

The Aviation FOSS

A methodology for conducting an Aviation FOSS is shown in Figure 3. The five phases of the generic FOSS methodology are noted. The Aviation Issues Assessment is composed of the Issue Evaluation and the Analysis-Level Decision. Issue assessment is the process of identifying and defining critical aviation issues in a manner suitable for analysis. In this phase is a task which determines the level of analysis required to respond to the study EEA. This level is consistent with the employment doctrine for aviation and with the battle function requirements specified for aviation units. Next, the methodology calls for the compilation of study data. This is phase II. It includes the task of data acquisition, development of an Aviation Systems Data Base, and the definition of an Aviation force structure. The Aviation Systems data base contains both current and projected aviation systems. Acquisition of data is done for those aircraft and functions to be examined. Only data for aviation systems capable of performing the postulated battle functions are stored. This data is passed on to the FORCE Development process. Within Force Development, the aviation force under analysis is structured. Three options are possible (1) structure according to present TOE, (2) structure according to a modified TOE, or (3) structure according to a conceptual TOE. In any case, the result of the Analysis Object Force, which is then inputted to Phase III, Basic Analysis. This analysis is equivalent to a COEA and includes an effectiveness analysis, a cost analysis and a cost/effectiveness (C/E) integration. The C/E results form the basis to do parametric analysis. Either sensitivity analysis or optimization is possible. The feedback to the methodology for either option is indicated in Figure 3.

Several Aviation FOSS products can be identified. First, a comprehensive and centralized Aviation Systems Data Base is created. This serves as an information repository for all Aviation studies. Second, standardized analysis techniques for aviation studies are developed. This includes flight profiles, Automated Force Structuring models, mission scheudlers, etc. These tools can certainly be applied to various aviation studies. Finally tne Aviation FOSS can validate post ARCSA-III issues and provide input to the upcoming Aviation Systems Program Review.

The Engineer FOSS

The methodology for conducting an Engineer FOSS is shown in Figure 4. This methodology is the basis for an on going effort sponsored by the Engineer School, Fort Belvoir, VA. A full description of tnis methodology is contained in the Engineer FOSS Study Plan (Ref 5).

The Engineer FOSS methodology parallels the generic FOSS methodology. The five phases of the study are evident. In Phase I an evaluation is made of the Engineer issue, namely "What is the contribution of the Engineer equipment to the combat effectiveness of the Combined Arms Team?" This issue is addressed at the division level in order to respond to the EEA generated by this issue.

In phase II, specific scenarios and force structures are defined. To this end, SOCRES Europe I, Sequence 2a and the 3rd Armored Division are selected. Characteristics for the Engineer equipment, contained in the Engineer FOSS data base, are used to develop a force structure for an engineer battalion and to define its corresponding mission requirements. This set of force descriptors constitutes the analysis package and is used as imput to phase III.

Phase III is an analysis of the cost and the Engineer Battalion and of the contribution it makes to total force effectiveness by performing its assigned scenario tasks. The DIVWAG and CARMONETTE models are the tools used for this analysis. Force cost is derived using the FCIS and standard costing techniques. Integration of the cost and effectiveness results is also done in this phase.

A sensitivity analysis (Phase IV) is next performed to determine the structure of the Engineer Battalion which makes the maximum contribution to the operations of the scenario force.

In phase V, the Engineer FOSS will formulate recommendations based on the analysis results, in the following areas: (1) Engineer Battalion Force Structure, (2) Engineer Battalion Performance Gaps, (3) Effectiveness and utility of present and proposed engineer equipment, and, (4) Identification of Engineer tasks in the Corp area.

These recommendations constitute the Engineer FOSS products.

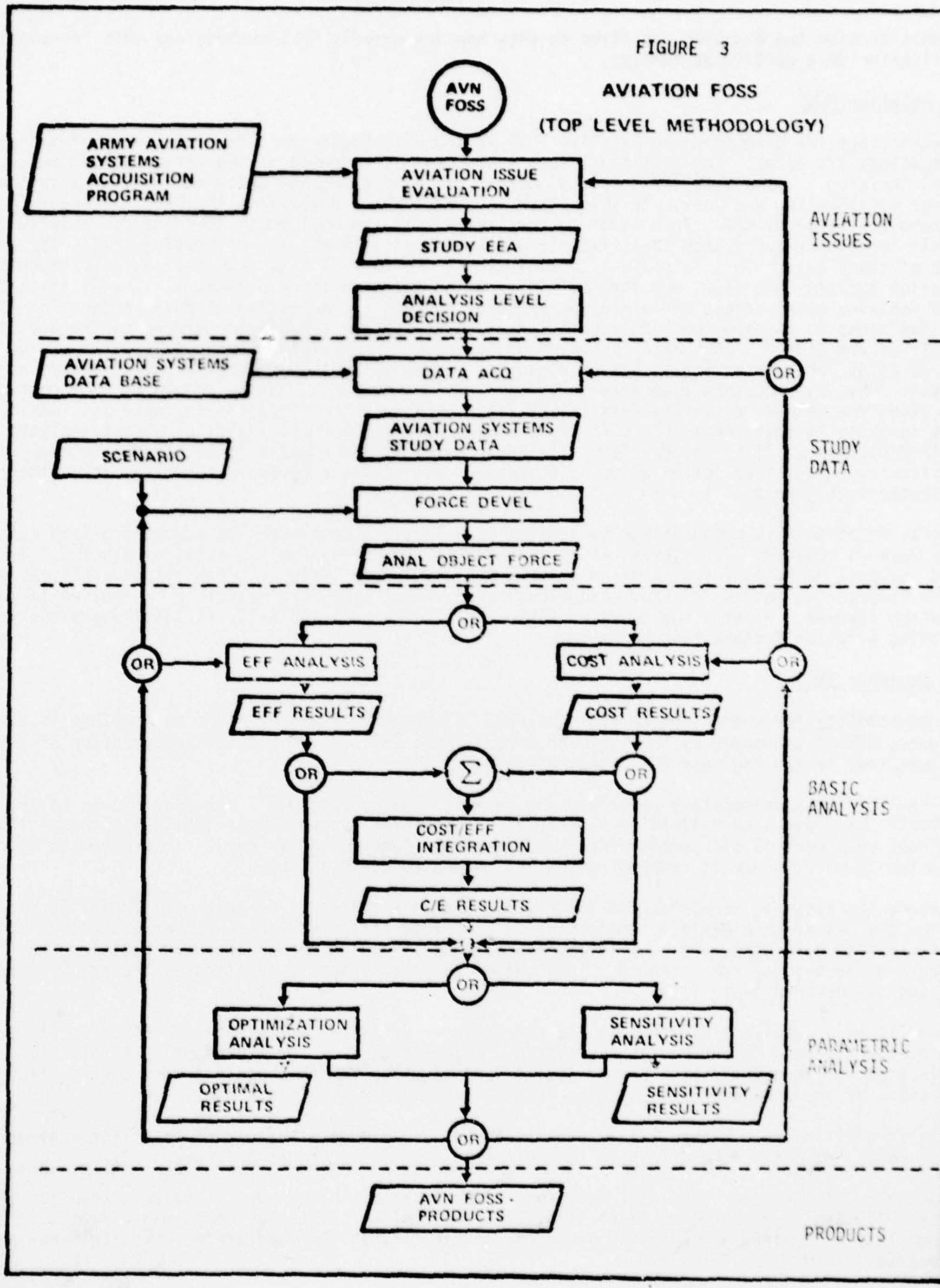


FIGURE 3

AVIATION FOSS

(TOP LEVEL METHODOLOGY)

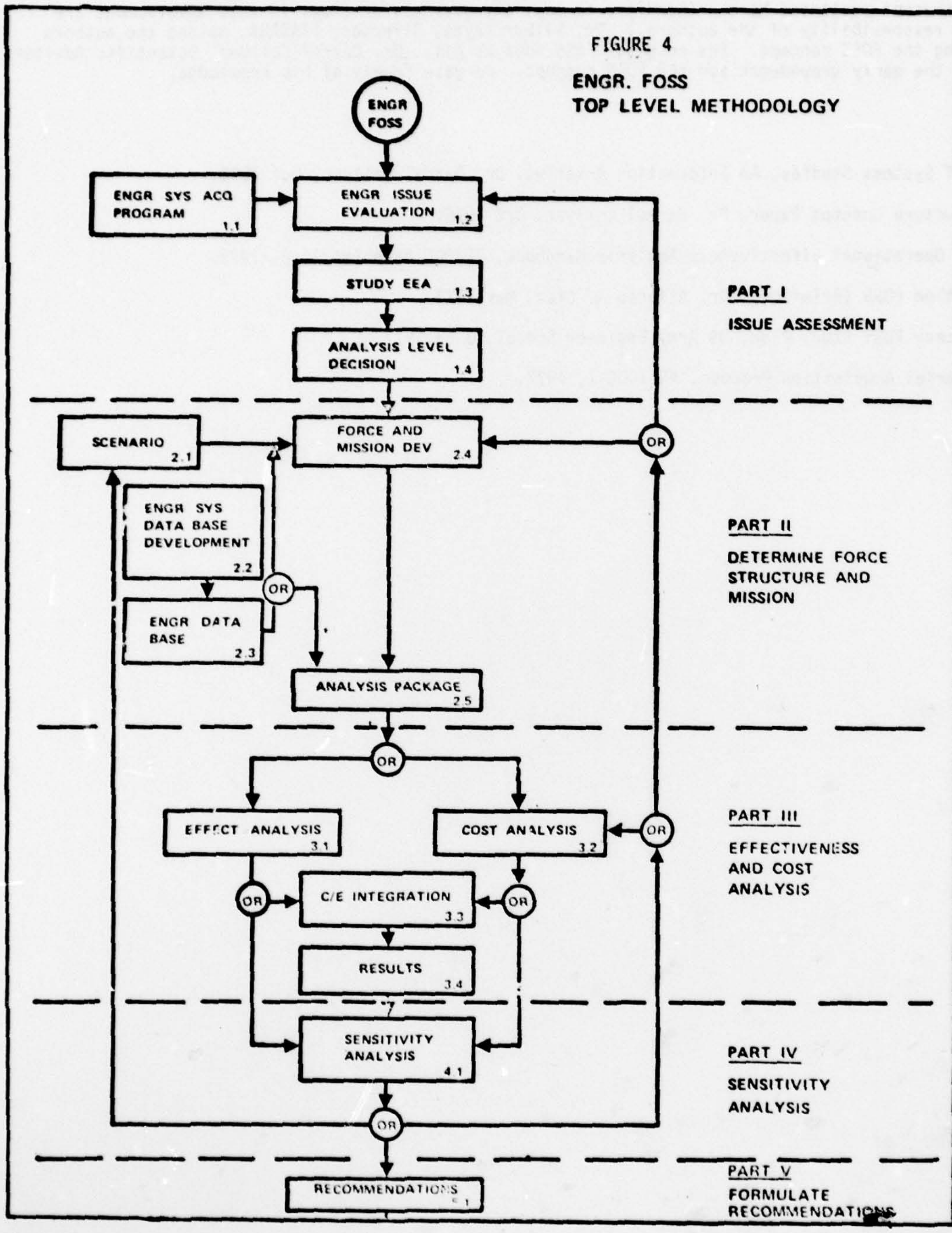


FIGURE 4
ENGR. FOSS
TOP LEVEL METHODOLOGY
ENGR FOSS
ENGR SYS ACQ PROGRAM 1.1
ENGR ISSUE EVALUATION 1.2
STUDY EEA 1.3
ANALYSIS LEVEL DECISION 1.4
PART I
ISSUE ASSESSMENT
SCENARIO 2.1
FORCE AND MISSION DEV 2.4
OR
ENGR SYS DATA BASE DEVELOPMENT 2.2
ENGR DATA BASE 2.3
ANALYSIS PACKAGE 2.5
PART II
DETERMINE FORCE STRUCTURE AND MISSION
EFFECT ANALYSIS 3.1
COST ANALYSIS 3.2
C/E INTEGRATION 3.3
RESULTS 3.4
PART III
EFFECTIVENESS AND COST ANALYSIS
SENSITIVITY ANALYSIS 4.1
PART IV
SENSITIVITY ANALYSIS
RECOMMENDATIONS
PART V
FORMULATE RECOMMENDATIONS

Acknowledgement

The authors wish to acknowledge the contributions of two individuals who influenced them in the formulation of the FOSS concept presented here. (Needless to say, any weakness or flaws in this development are strictly the responsibility of the authors.) Dr. Wilbur Payne, Director, TRASANA, guided the authors in formulating the FOSS concept. The original FOSS idea is his. Dr. Darrel Collyer, Scientific Advisor, TCATA, layed the early groundwork for the FOSS concept. He gave freely of his knowledge.

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TITLE: Army Dollar Resource Allocation Model - ADRA II

AUTHOR: Daniel J. Shedlowski

ORGANIZATION: US Army Concepts Analysis Agency

ABSTRACT: The ADRA II Model is a computer-based set of programs which describes a functional relationship between the Army's budget and the Army's warfighting capability. This relationship allows the use of the ADRA Model in analyzing proposed or directed budget changes. The functional relationship between the Army's budget and its warfighting capability is developed in a two step process. First, the Army is viewed as an economic system and the econometric technique of input-output analysis is applied to the current Army fiscal program. The input-output analysis provides an estimate of the dollar changes in all "economic sectors" of the Army which would result from dollar changes in any sector of the budget. In the second and final step, the sectors of the Army are linked to a numerical measure of the Army's warfighting capability. Algorithms were established to allocate the measure of warfighting capability among the Army sectors. This presentation will discuss the background and development of the ADRA prototype model and plans for its future development and use within the PPBS cycle.

SUBJECT: Army Dollar Resource Allocation Model - ADRA II

AUTHOR: Mr. Daniel J. Shedlowski

AGENCY: US Army Concepts Analysis Agency

I. Introduction. The ADRA II Model is a computer-based set of programs which describes a functional relationship between the Army's budget and the Army's warfighting capability. This relationship allows for the use of the ADRA Model in analyzing budget changes (actual or potential), preparing alternatives and evaluating their impact on combat capability.

II. Purpose. The ADRA Model provides a link, at a macro level, between budget dollars and capability. Since the objective of the Army budget is to provide for combat capability, it is logical to expect that a relationship exists between budget and capability. The formal definition of this functional relationship via the ADRA Model provides a valuable analytical tool for evaluation of budget changes. Since the relationship is formally defined and delineated, it can be applied, reviewed, and most importantly, improved.

III. Background. The formal definition of a functional relationship between budget and combat capability was first investigated at CAA in a February 1976 study sponsored by the then Under Secretary of the Army, Norman Augustine. This study, which is referred to as the "100 Day" study since it was completed in approximately 100 days, proposed a candidate methodology for linking budget and capability. The "100 Day" study is an important predecessor of the current ADRA II Study because it demonstrated the feasibility of establishing a relationship between budget and capability. The on-going ADRA II Study represents a continuing refinement of the "100 Day" study methodology. Extensive sensitivity testing and in depth reviews of the model algorithms were conducted and reported in an ADRA II interim report that was published in April 1977. An interactive, self instructional version of the ADRA Model has been transferred to the headquarters, Department of the Army, computer environment. This computer based model allows for quick reaction ADRA evaluations in response to direct queries from Army analysts. The present ADRA II Study efforts include continuing investigation into model refinements and monitoring the trial period of the ADRA Model in its usage by Department of the Army staff analysts during the PPBS cycle.

IV. Model Methodology. The ADRA Model methodology can be divided into two major steps: (1) input-output analysis and (2) capability analysis. The following discussion of these steps corresponds to the diagram in Figure 1 which portrays a simplified example of the operation of the ADRA Model.

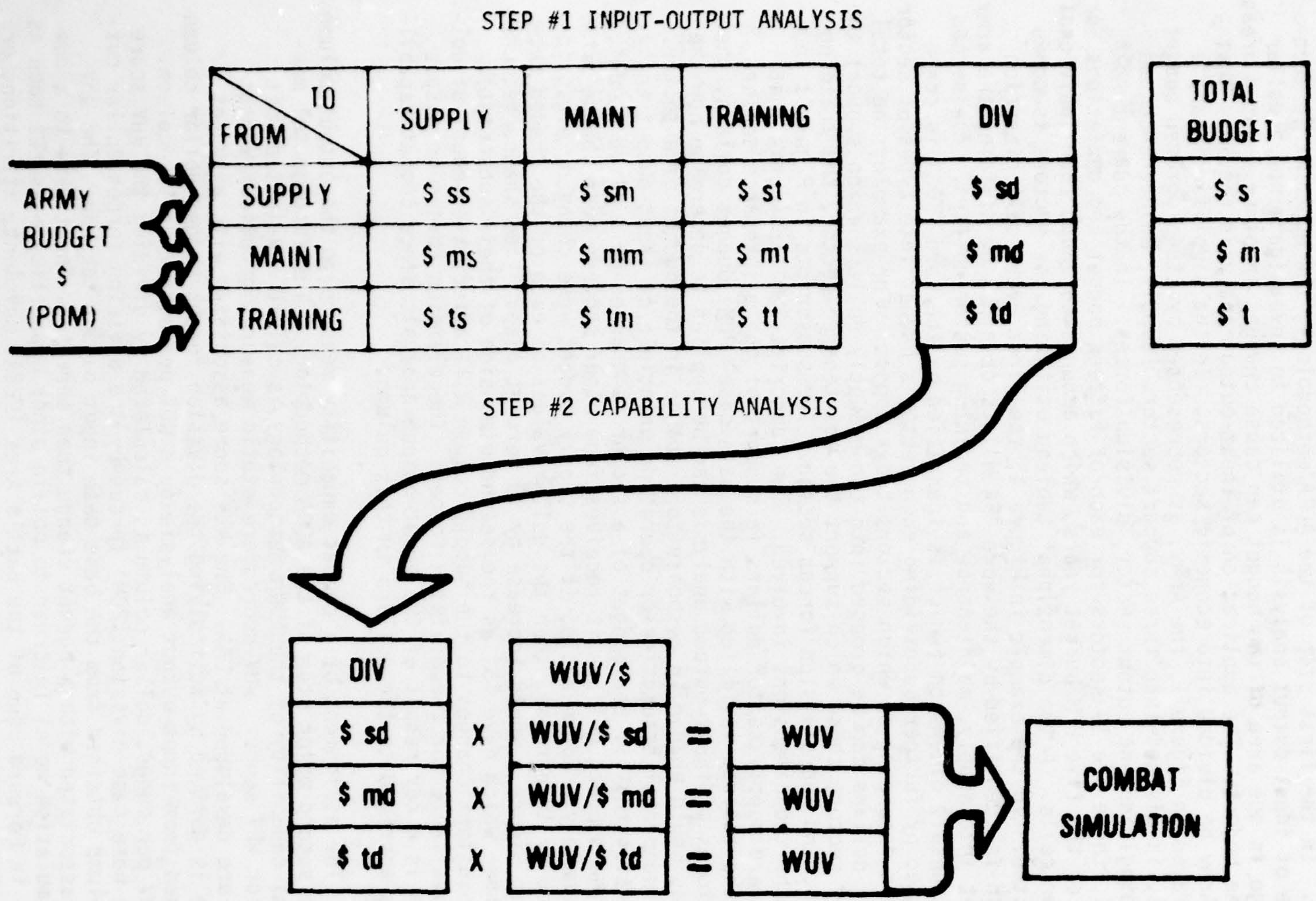

Figure 1, ADRA Methodology (Simplified)

A. In the first step of the ADRA methodology, the econometric technique of input-output analysis is utilized to investigate how a dollar change in one area of the budget can cause changes in other related areas of the budget. The application of input-output analysis requires that the Army be divided into economic sectors. In the simplified example portrayed in Figure 1, the Army, as represented by its programed budget (POM), is divided into three support sectors (supply, maintenance and training) and one output sector, division forces. In the current ADRA Model, there are 19 sectors for each of fifteen budget appropriations for each of the five POM budget years, which amounts to about 1500 individual sector cells. A two dimensional tableau utilizing the sectors is constructed. In the example in Figure 1, the first (vertical) dimension (which is identified by the word "FROM") is obtained by dividing the army budget into supply, maintenance and training sector dollars. The second (horizontal) dimension (which is identified by the word "TO") is constructed by further subdividing each sector's budget into types of sector dollars depending on which sectors they support. For example, the total supply dollars can be grouped into those supply dollars which support the supply sector, those which support the maintenance sector, the training sector, and the division forces sector. The subscripts in Figure 1 indicate the two dimensions involved. The subscript "SM" indicates that these are supply sector dollars in support of the maintenance sector. Once the tableau is filled with the base case (POM) budget dollars, the techniques of input-output analysis can be applied to determine how the tableau would change in response to a change in the budget of a sector. The fundamental assumption or operating principle of input-output analysis states that if the budget of a sector is changed by a given amount, then the support dollars it receives from other sectors must change proportionately. For example, if the supply budget were changed, e.g., increased by 10 percent, then the dollar values of each of the shaded sectors in Figure 1 would increase by 10 percent also. (The shaded sectors are those which have "S" as the second dimension of their subscript). The resultant changes to the supply column will affect the amount of dollars available for the division forces. The division forces or output column is a key result of the input-output analysis since combat capability is ascribed to the dollars in this column.

B. The assignment of a combat capability measure to the output column is the second major step of the ADRA methodology. The fundamental measure of capability of the ADRA methodology is called a Weighted Unit Value or WUV score. WUV scores are static measures of effectiveness which are developed at CAA. The WUV score associated with a budget change is derived by multiplying the division forces budget dollar column obtained from input-output analysis by a WUV per budget dollar column. The WUV per budget dollar column is calculated by dividing the WUV score of the base case division (POM) forces by the division forces dollar output column obtained from the base case input-output tableau. The WUV score associated with a budget change then serves as input data to a combat simulation model in order to obtain other capability measures such as change in Forward Edge of the Battle Area (FEBA) movement, attrition, or other appropriate measure of capability. All capability change values output by the ADRA Model are expressed in terms of change with respect to the base case budget/capability.

V. Model Implementation. The methodology description in the previous paragraph was deliberately simplified in order to convey an understanding of the fundamental operating principles of the ADRA Model. However, the actual operating model is highly complex, particularly with respect to number and types of dimensions involved. For example, in the input-output analysis portion of the model calculations are made for approximately 1500 individual sector cells. Although the methdology is much too complex to allow for manual calculation, it lends itself ideally to computerization because of the predominance of matrix operations involved. The system design of the computer based model includes two separate but directly related modes of operation: (1) a batch mode which is called model calibration and (2) an interactive mode which allows for direct user inquiry and response. These two modes are outlined in Figure 2.

A. In the calibration or batch mode, all of the input-output coefficients (these coefficients indicate the amount of sector support dollars required per dollar change of a sector budget) and the WUV per dollar factors are calculated to develop a data base for the interactive model. The data output from the calibration operation only requires updating when a new base case budget is available. An update or recalibration is usually performed whenever a new or revised FYDP is available. The calibration operation also serves to reduce the core storage and calcualtion requirements during the interactive mode, thereby providing for quick response to user queries.

B. Once a data base has been generated by execution of the calibration portion of the ADRA computer-based model, the interactive portion of the model accesses this data base to generate responses to user queries. The interactive model is self instructional and contains editing routines which detect user entry errors and indicate corrective actions. The user can submit a proposed budget dollar change to the model at any one or combination of three hierarchical levels which in descending order are as follows: (1) total year budget, (2) total appropriation budget and (3) total sector budget. The ADRA interactive program will respond with the estimated capability impact associated with the budget change entered by the user. Since the input-output analysis requires that a budget be specified at the sector level of detail, a model algorithm is used to determine sector budget changes if they are not prescribed by the user. If a budget increase is desired and the sector detail is not specified, the budget dollars of each eligible ADRA sector are increased in direct proportion to the base case budget value and WUV per budget dollar value ascribed to the sector. If a budget decrease is desired the same rule is applied with the exception that the decrease is in inverse proportion to the WUV per budget dollar value of the sector. This method of sector budget selection seeks to attain the highest combat capability associated with a budget change while maintaining a balance among the sector budgets.

C. In using the interactive model to evaluate a budget change, the analyst normally enters his specific budget change at the sector level of detail and receives a response which indicates the potential capability impact associated with the change. If the analyst desires an ADRA generated alternative, he then enters the budget change but does not specify the sector, ie., only the year or appropriation dollars are specified.

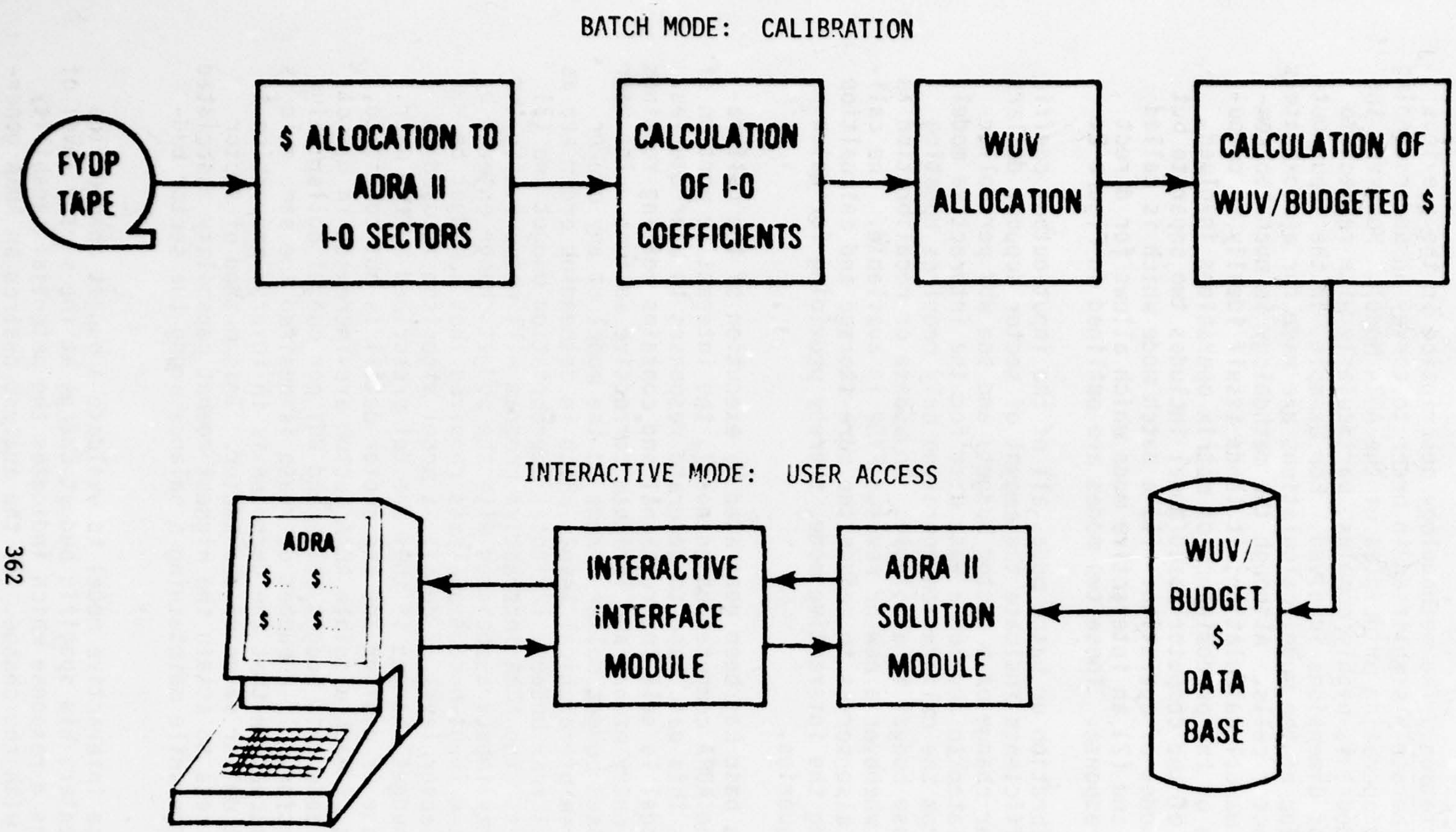

Figure 2, Implementation of Computer Based Model

The interactive model responds with an alternative proposal for the budget change that was previously entered at the sector level of detail. The alternative proposal is presented at the sector level of detail (the sectors having been selected by the model algorithm) along with its estimated impact on combat capability. After reviewing the alternative proposed by the model, the analyst can intervene by altering specific sector budget values of the solution and explore the combat capability input of this user modified solution. The user entries and model responses are displayed on the CRT screen of the interactive terminal and an option for a companion hardcopy printout is available.

VI. ADRA Applications. The ADRA is currently undergoing a period of trial usage by Army Staff analysts with CAA guidance. The trial period, which began during the FY 79-83 POM program review phase, covers one complete POM cycle (see Figure 3). An ADRA analysis of the combat capability impact of the major issues proposed by OSD has been recently completed. Future ADRA applications include an evaluation of Program Budget Decisions (PBD's) and POM program formulation proposals, thereby completing the POM cycle test period. The ADRA Model is reclaibrated with each FYDP update shown in Figure 3. The ADRA Model is typically used in the POM cycle to evaluated program/budget changes proposed by the Army and/or OSD. The ADRA evaluation consists of an estimation of the combat capability impact of the proposed change and an alternative ADRA plan(s) which seeks to provide more combat capability for the same dollar amount of change. The model is also used for quick reaction evaluations of budget proposals which are not normally part of the POM cycle. Upon completion of the POM cycle test period a final report to include complete model documentation will be published in March 1978.

VII. Example of ADRA Use. The model operation can best be described by an example of the results produced by the model in the evaluation of a proposed budget change. In order to maintain the unclassified nature of this paper, the model input and output data is illustrative and does not represent an actual ADRA evaluation of a budget proposal. Assume that a decrement to the Army budget is proposed by OSD. The proposal calls for a total budget decrement of 2.7 billion dollars over the 5 POM years as outlined in Table 1. The dollar values by appropriation and sector (all values were designated for the division forces sector) were entered as input data to the interactive model for each of the five POM years. The resultant capability impact is indicated by the 'OSD Directed' line in Figure 4. The capability impact is measured in terms of the percentage difference from the capability of the POM base case force, where capability is determined by comparison of FEBA movement or attrition results. Two alternative plans for the same budget decrement as that proposed by OSD were generated by the ADRA Model. The first alternative maintains the same appropriation dollar totals as in Table 1, but the changes to the sector budgets within the appropriation were selected by the ADRA Model algorithm. This solution is called the constrained solution in Figure 4. The second, unconstrained solution, maintains the same total dollar change for each of the years as in Table 1, but the ADRA Model algorithm was utilized to choose both the appropriations and the sector budget changes. The two ADRA alternatives offer a potential for improved combat capability at the same total budget decrement level as proposed by OSD.

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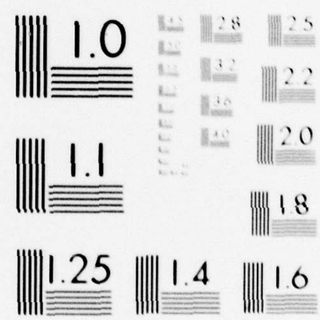
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2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

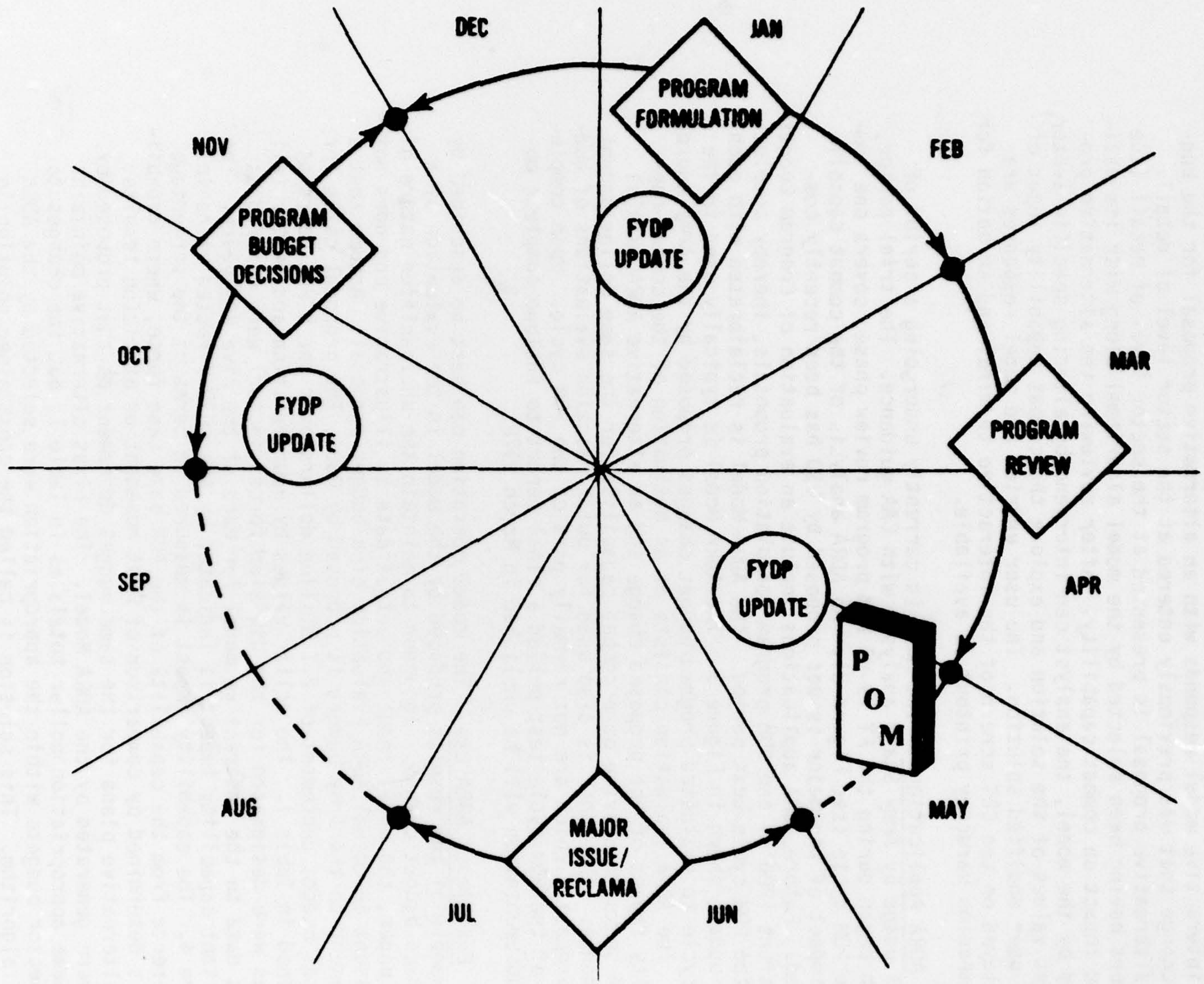

Figure 3, ADRA Applications During the POM Cycle

Table 1. Sample ADRA Input Data

Appropriation	FY 79	FY 80	FY 81	FY 82	FY 83
	Budget Change in Millions of Budget Dollars				
Aircraft	-25.0	-20.0	-15.0	-50.0	-75.0
Missiles	--	-5.0	-50.0	-90.0	-100.0
WTCV	--	-15.0	-80.0	-100.0	-180.0
Ammo	-220.0	-220.0	-220.0	-350.0	-400.0
OPA	--	-5.0	-100.0	-180.0	-200.0
Total Dollar Change	-245.0	-265.0	-465.0	-770.0	-955.0

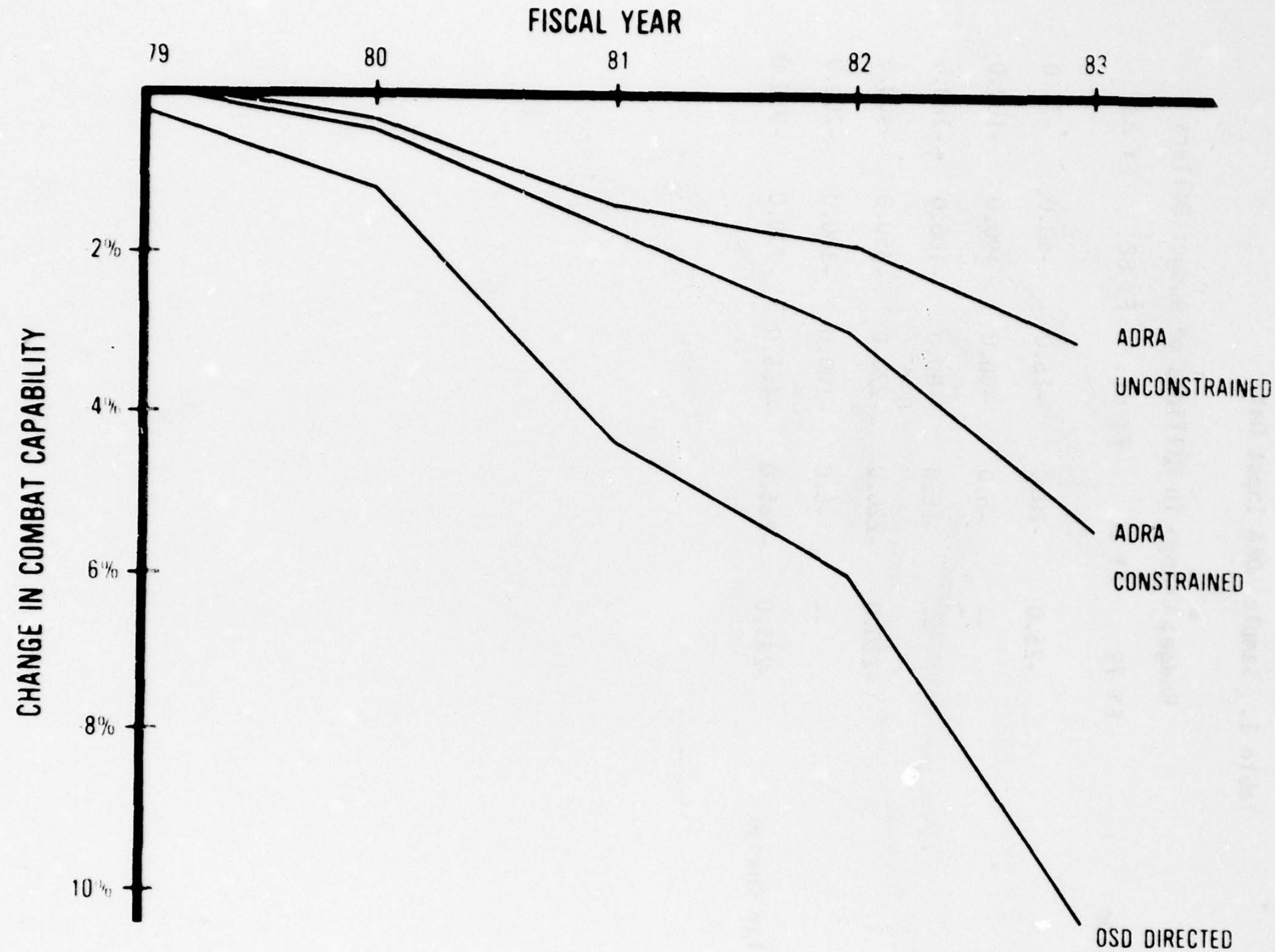

Figure 4, Sample Model Output

The ADRA Model provides a detailed listing of the appropriation and sector dollars which correspond to the two alternatives. Thus the ADRA Model was involved in two roles: (1) the combat capability impact of the OSD change was evaluated and (2) alternative budgets were proposed which indicated potential areas for budget decrements which would result in improved input capability over the OSD budget changes.

VIII. Summary. The purpose of the ADRA II Study is to develop, test and implement a methodology to assess changes in the Army's capabilities resulting from real or expected changes in Army budgets. A methodology for linking budget to combat capability has been developed and tested. A computer-based model which incorporates this methodology has been implemented. The computer-based model includes an interactive, self instructional model interface which allows direct user interaction in ADRA budget evaluations. This computer-based ADRA Model is currently undergoing trial usage by DA staff analysts for one complete POM cycle. Model development efforts will be completd March 1978 with the preparation of a final study report/model documentation.

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TITLE: The AMSAA/RARDE Combat Simulation

AUTHOR: Stewart J. Kempster

ORGANIZATION: Royal Armament Research and Development Establishment (UK), Exchange Scientist at US Army Materiel Systems Analysis Activity

ABSTRACT: This paper presents an overview of a simulation which is being jointly developed by the US Army Materiel Systems Analysis Activity (AMSAA) and the UK Royal Armament Research and Development Establishment (RARDE). In 1974, RARDE defined the requirement to develop a simulation in which the effects of minefields and barriers were accurately and realistically represented; no existing simulation was deemed to be adequate. This event-sequenced battalion-level simulation has been designed explicitly around this need and is an amalgam of features and methodologies employed in many other similar simulations in use in the western defense communities.

A description of the structure of the simulation is given along with an outline of the presently implemented models and the enhancement plan to be followed to the end of 1979.

TITLE: The AMSAA/RARDE Combat Simulation

AUTHOR: Stewart J. Kempster

ORGANIZATION: Royal Armament Research and Development Establishment (UK), Exchange Scientist at US Army Materiel Systems Analysis Activity

This paper presents an overview of a simulation which is being jointly developed by the Army Materiel Systems Analysis Activity (AMSAA) in the USA and the Royal Armament Research and Development Establishment (RARDE) in the UK. It describes the structure of the simulation and highlights some of the major features of the models that have been incorporated to date.

First, a brief history of the development of the simulation is given. An outline of the future activities for model enhancement is also given.

SIMULATION DEVELOPMENT

In late 1974, RARDE engaged on a development plan to produce a combat simulation to investigate the effects of minefields and barriers on battalion level actions. This course of action was precipitated by the need to investigate such obstacles and, after due consideration of the extant models, it was felt that none of these possessed the necessary attributes.

The approach then taken was to review a large number of battle simulations that had gained acceptance in the western defense communities and abstract their best features to form one simulation. As there appeared to be no acceptable representation of minefields and barriers, novel work was necessary in this area.

The AMSAA involvement came through their requirements for a more detailed combat simulation to complement their existing deterministic model; their involvement in the simulation was facilitated by an Exchange Scientist agreement between the two establishments.

SIMULATION STRUCTURE

The simulation which is presently evolving is of the event-sequenced type since this approach offered the flexibility which was desired to enable the representation of new military tactics and equipment to be achieved as quickly and easily as possible. The very nature of this approach ensures that a modular design is adopted which formalizes the interfaces within the simulation.

The simulation is a Monte Carlo type model since it is believed that, in many circumstances, the results of combat can be more easily understood than with the deterministic approach.

One of the main features of the simulation is the detail that is used. In an attempt to reduce the running time on a computer system, as much of the necessary calculation as is possible is performed on a once and for all basis through a system of preprocessors which pass relevant

information to the main simulation. All of the intervisibility and movement details are preprocessed in this way thus reducing very significantly the replication time of the simulation within the computer.

The orders which determine the movement of vehicles across the battlefield are of the conditional type which will allow the future course of action to be followed by one unit to depend on the action of other vehicles. Further, the routes that are specified for the units are such that they include branch points where the unit must make a decision as to its future movement pattern. This is particularly important in providing a tactically realistic model of a minefield or barrier encounter.

To ease the burden of the analysis of simulation results, a post-processor is being designed which will allow easy generation of statistics for presentation.

Presently, the following models have been implemented both within the main body of the simulation and through the system of preprocessors:

Terrain

Movement

Detection

Direct Fire

Indirect Fire

Minefields and Barriers

TERRAIN

Terrain is modelled through a preprocessor system which passes details on level of exposure of a target to a particular observer to the main simulation.

The resolution of the terrain is theoretically a variable within the simulation but the practicalities of data collection suggest that spot heights at 100 metre intervals is that which will be used.

For each observer-target pair, the information passed to the simulation takes the form of the existence or otherwise of a line-of-sight and, if there is existence, the amount of the target that is exposed taking account of the height above the ground of the observers sensor system and the physical size of the target unit. The height of the vegetation is also considered in this calculation. The height of each unit above ground zero is calculated by interpolation from the terrain height information that is supplied to the preprocessor.

For a moving unit, the information passed to the main simulation is given when the unit reaches the boundary of a grid square the size of which is defined by the resolution of the terrain data in use.

MOVEMENT

Units are constrained to move along prespecified route streams; the distinction that must be made here is that route streams contain branches, routes that can be taken if the tactical situation dictates. These branches originate at decision points, the route to be taken depending on a prespecified decision plan or on an a prior decision that has been specified in the order set for the particular unit.

At present, these decision points have been implemented in conjunction with minefields and barriers to determine which crossing method is to be used. However, a similar methodology could be used to model such events as the tactical reaction to smoke and the tactical response of an attacking formation to being involved in an intense fire fight.

The movement of vehicles across the terrain is simulated through a preprocessor which takes account of the terrain characteristics of the ground over which the unit is moving. The model combines the vehicles weight and automotive system output capability with the soil characteristics and route gradient to produce a maximum possible speed across a particular segment of a route under consideration. For a unit to stop at a point on a route, the braking capabilities of the vehicle are simulated to determine the point at which braking must commence and the effect that this will have on the speed of a unit on the particular route segment.

An investigation of this model is presently being made to determine its sensitivity as it is felt that it may be over-complicated in some areas. The results of this activity are not presently available.

DETECTION

As mentioned above, lines-of-sight begin when a unit crosses the boundaries of a square. Fresh calculations are made when a new grid square is entered.

Once a line-of-sight does exist, the detection process is triggered by the normal search process. A detection time is generated by taking account of such conditions as the posture of the observing and target units, the range between the units, the sensor system that is being used and the level of target exposure. A detection event is then scheduled for a future time.

However, this process can be circumvented by the trigger of a launch signature cue. The same basic process is followed but it is assumed that, after a short time, the process reverts to the normal search process. If a detection is made from this trigger, the time to detect suitably reflects that the search area has been restricted.

When the conditions governing the detection time significantly change, for example when the target's level of exposure increases or decreases or if there is a change in the crossing component of its velocity, a suitable change is calculated in the scheduled detection time. The basis

of the statistics employed in this calculation is that the information gained to the point in time when the conditions changed is not lost; the time to gain the present level of information in the new conditions is calculated and the further information necessary to detect the unit is determined stochastically.

When a line-of-sight terminates, the information already gained is not automatically lost whether a detection has occurred or not. All information is retained for a specified input time at which all is lost if the line-of-sight has not reopened.

The central point of this detection model can best be described as the theory of conservation of information.

This model represents only visual detection; however, plans have been made to re-specify the methodology so that a representation of electro-optical devices is achieved. The likely methodology to be used is that developed by the Night Vision Laboratories, the details of which are contained in another of the symposium papers.

DIRECT FIRE

Once a detection has been made, the target/weapon selection process is entered. Here, the possible weapons and ammunitions that the firing unit has available to engage the target (taking account of past engagements by depletion of the stocks of each round type which the unit originally possessed) are considered to determine a net worth figure for the potential engagement. The combination with the highest worth is selected as the weapon/ammunition pair that will be used.

If more than one target is available, the same process as just described is undertaken for each potential target. The target with the greatest worth is then selected to be engaged but it is engaged only if the worth as calculated is more than a threshhold value.

The engagement process is then entered; delays caused by the loading and laying processes and the time-of-flight of the munition are calculated to determine the time at which the casualty assessment will take place. At this stage, the obvious checks to determine that the line-of-sight remains in existance are made to determine if the round is fired and, if it is fired, whether it is lost by the target going out of the firing unit's field of view.

The casualty assessment generates one of the following results:

Miss

Hit no damage

Mobility kill

Firepower kill

Mobility and Firepower kill

Complete kill

Each of these results has a specific effect on the target regarding its future capability as a combat unit, viz. its observation, firing and movement capabilities and its status as a future target. If no damage results, i.e., the casualty assessment determines that a hit-no-damage or a miss occurred, a new engagement is initiated so long as the conditions of continued line-of-sight existence and ammunition availability are satisfied.

If a second round is fired, a reduced time of loading and laying is used since only a fine lay will be required.

Only an input number of rounds may be fired in a particular engagement; when this number has been fired, the engagement process is automatically terminated and the search process continues until another target, which could be the one just vacated, is selected.

INDIRECT FIRE

The indirect fire model incorporated within the simulation allows the simulation of pre-planned and target-of-opportunity engagements.

The model simulates the artillery structure from the forward observers transmitting information to the fire direction center who coordinate this and transmit fire missions to the artillery batteries. The link from the forward observer to the artillery battery when an engagement is in process is also simulated.

Before any information can be transmitted from one element of the artillery structure to another, the communication queues are simulated to generate the delays which can occur.

Presently, the effects of high explosive munitions are all that are assessed but the model has been designed to accommodate other types of ammunition that could be available.

The model as implemented takes account of the delivery accuracy of the particular artillery systems being simulated in determining where the fired rounds actually fall. Adjustment by the forward observer can be simulated. Also, the firing rate capabilities of the batteries is represented in order to ensure that the desired delivery rates are possible.

MINEFIELDS AND BARRIERS

When a minefield or barrier is encountered by a unit, a decision process is entered to determine the method of crossing or whether the obstacle should be avoided by movement around it using a route branch. This process involves the inspection of the order sets of the encountering units to determine if an a priori decision has been given. If a computed decision is to be made, the philosophy used is that of minimization of delay taking account of the involved unit's capabilities of negotiating the obstacle.

Engineer effort is represented as a resource within the model and the present situation is inspected to determine the availability of the necessary resources to improve the obstacle. The time delay that the employment of engineer support will cause is used in the calculation of the method of negotiating the obstacle.

Casualties may be suffered in crossing a minefield. These are determined from the density of the minefield or from the structure of the minefield taking account of the effective width of the tank. The devices which a unit has are assumed to be deployed and all other units traveling with it are assumed to follow a tactical formation with the breaching unit.

The two minefield representations described permit simulation of both the conventionally laid minefield with defined types and positions of mines and the remotely delivered minefield with its density depending on the features of the delivery system.

FUTURE PLANS

Immediate plans for the development of the simulation require that representation of suppression and smoke effects be undertaken by the US and a complete representation of remotely delivered mines be undertaken by the US. The suppression model to be incorporated has been developed by the UK and is a representation of both direct and indirect fire effects.

The basis of the indirect fire suppresssion is a calculation of the intensity of fire being brought down upon a unit and has been developed from World War II data. The direct fire suppression is to be represented as a function of miss distance; the effects in this representation are more subjectively defined because of the lack of data in the UK.

However, both areas to be represented will have to be reviewed by the US in the light of data available to them from the Arab-Israeli conflicts.

The representation of smoke effects within the simulation is the other short-term improvement to be undertaken by the US. The development of methodology for the representation of smoke cloud generation, transport, and decay is underway for other simulations and this work will be used for this simulation. However, the suppression effects of smoke will need representation within the model as will the representation of electro-optical surveillance devices referred to above. It is anticipated that these tasks will be completed by mid-1978.

The UK are to generate a representation of the use and effects of remotely deliverable mines. This has not been previously undertaken as the indirect fire methodology has only recently been incorporated within the simulation. This model will initially explicitly represent delivery by indirect fire units and direct fire units; the use of helicopter delivered munitions will be represented implicity as a combat resource.

Work is to be undertaken in the simulation administrative area. By the end of 1977, a complete sensitivity analysis of the simulation is to be undertaken by the US.

Further, optimization of the computer code is to be undertaken in an effort to increase the speed and efficiency of the simulation. Timing runs are to be made to determine which models within the simulation are the most time-consuming so that those areas may be investigated further to determine if methodology changes should be considered if computer time appears to be a problem.

The development plan for the simulation extends until 1979 by which time it is planned that representations of electronic warfare, helicopters, false targets, jockeying and reliability, availability and maintainability are included. However, the simulation will be in a state whereby studies can be undertaken using this as the major analytical tool in early 1978.

TITLE: Simulating Combat Under Degraded Visibility

AUTHORS: Mr. Kent Pickett (US Army Combined Arms Combat Developments Activity), Mr. Thomas Cassidy (US Army Night Vision Laboratory), Mr. Frederick Campbell (US Army Materiel Systems Analysis Activity)

ABSTRACT: In November 1976 a joint project was undertaken by the Army Materiel Systems Analysis Activity (AMSAA), the Night Vision Laboratory (NVL), and the Combined Arms Combat Developments Activity (CACDA) to produce a combat simulation model to represent night combat. The purpose of this paper is to describe the resulting model and the work conducted with it in support of the Joint Technical Coordinating Group/Munitions Effectiveness Special Task on Illumination Effectiveness.

The night Combat Model represents a battalion attacking a defending company. The model was developed to represent four facets of night combat:

- The effects of movement and terrain on both forces at night
- The effects of both natural (moon, stars) and artificial (flares, burning vehicles) illumination sources on night combat
- The effects of vision devices (optical, image intensifier and thermal) on the ability of crews to detect and engage targets
- The resulting attrition of both forces when engaged in a day or night environment

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AUTHORS: Mr. Kent Pickett (US Army Combined Arms Combat Developments Activity -CACDA); Mr. Thomas Cassidy (US Army Night Vision Laboratory - NVL); Mr. Frederick Campbell (US Army Materiel Systems Analysis Activity (AMSAA)

I. INTRODUCTION

A. In November 1976 a joint project was undertaken by AMSAA, NVL, and CACDA to produce a combat simulation model to represent night combat. The purpose of this paper is to describe the resulting model and the work conducted with it in support of the Joint Technical Coordinating Group/Munitions Effectiveness Special Task on Illumination Effectiveness.

B. The Night Combat Model represents a battalion attacking a defending company. The model was developed to represent four facets of night combat.

1. The effects of movement and terrain on both forces at night.

2. The effects of both natural (moon, stars) and artificial (flares, burning vehicles) illumination sources on night combat.

3. The effects of vision devices (optical, image intensifier and thermal) on the ability of crews to detect and engage targets.

4. The resulting attrition of both forces when engaged in a day or night environment.

The next section of this paper describes the Night Combat Model and how it was used to simulate the battle scenario. The final section is devoted to a discussion of the results from a recent study using the Night Combat Model.

II. THE NIGHT COMBAT MODEL

A. The basic structure of the Night Combat Model is shown in Figure 1. The model consists of four modules and must be run in three phases in order to simulate the night battle. The mobility module (DYNTACS movement routine) is executed first, providing a record of the location of the elements for both forces throughout the battle. The second phase consists of running the illumination module (COIL) to calculate the illumination level at each element on the battlefield throughout the battle. Finally, the AMSAA War Game (AMSWAG) and the NVL detection module are run interactively to determine the attrition sustained by both forces furing the night battle.

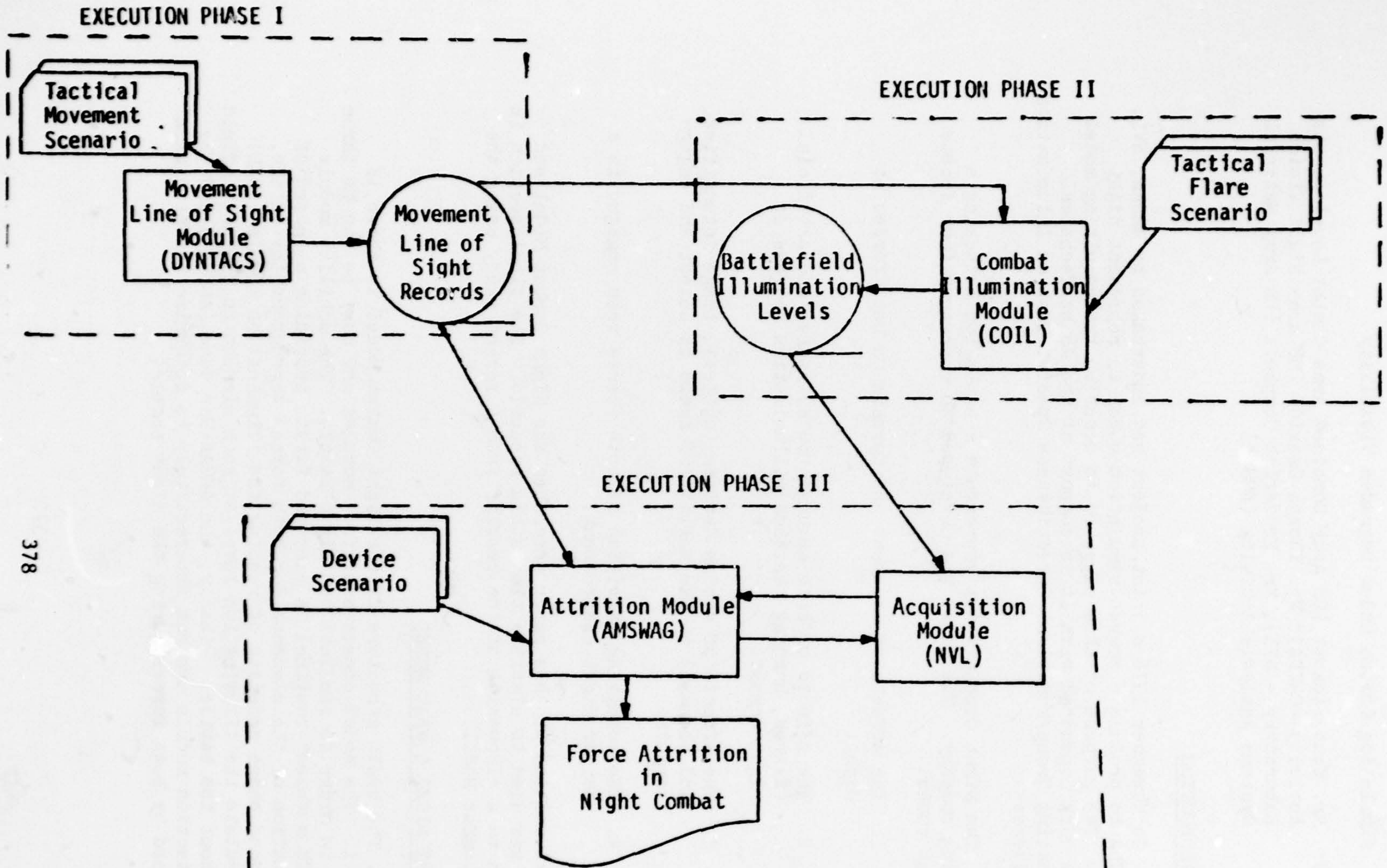

Figure 1. Logic Structure of the Night Combat Model

B. The following paragraphs contain a description of each module with emphasis on those features which pertain to this overall simulation. References 1 through 7 provide general, and in some cases detailed, documentation of the mobility, illumination, acquisition and attrition modules. All four modules have been used in previous studies; however, this effort represents a conglomorate of these models. Weapon systems with explicit version devices (optical, image intensifier, and thermal) can now respond to the variable conditions throughout the war game simulation

C. <u>The Movement Module</u>

1. The Movement Module calculates the tactical movement, locations, and line-of-sight status of all elements during the engagement. The module was built using the movement and line-of-sight subroutines from Dynamic Tactical Simulator (DYNTACS) Combat Model. A complete description of the model can be found in Reference 1 of the bibliography. Consequently only the most salient features of the model will be discussed here.

2. The terrain data base is utilized in all calculations made by the model. This data base consists of a digitized map of the terrain area describing the terrain contours, vegetation types, and soil trafficibility in the battle area. An example of the computerized data base used by the mobility module is shown in Figure 2. This figure was drawn by the graphics portion of the mobility module and represents the terrain features as the model "sees" them.

3. A tactical data base is also provided to the model. This data base represents the initial locations for both attacker and defender elements. Points along the movement route for each element must also be provided to the model. These points provide the model with a generalized pattern of the movement. The actual route taken by each element is selected by the model based on terrain contours, concealing vegetation, and suspected enemy position. The model uses the terrain data base to select a route that minimizes an element's exposure to a suspected enemy position. Figures 3 and 4 show the movement traces generated by the model for a night scenario. Figure 3 shows attacker and defender movements during the first 11 minutes of battle. It will be noted that the TOW in position 10 has begun to drop back as a result of pressure from the BMP. Movement for the entire battle is shown in Figure 4.

4. Although the terrain contours have been deleted from Figures 3 and 4 for purposes of clarity, the model uses this data base in all movement calculations. The data base is also used to calculate "line-of-sight" between each attacker and defender vehicle during the battle. The term "line-of-sight" is used in this paper to describe an unobstructed field of view between an attacker and defender element. In a geometrical sense, the model draws a line between an attacker and defender element. If this line is not blocked by a terrain or vegetation feature then "line-of-sight" is said to exist. The existence of "line-of-sight" between two elements provides only the opportunity for detection and later engagement. It will be noted in the discussion

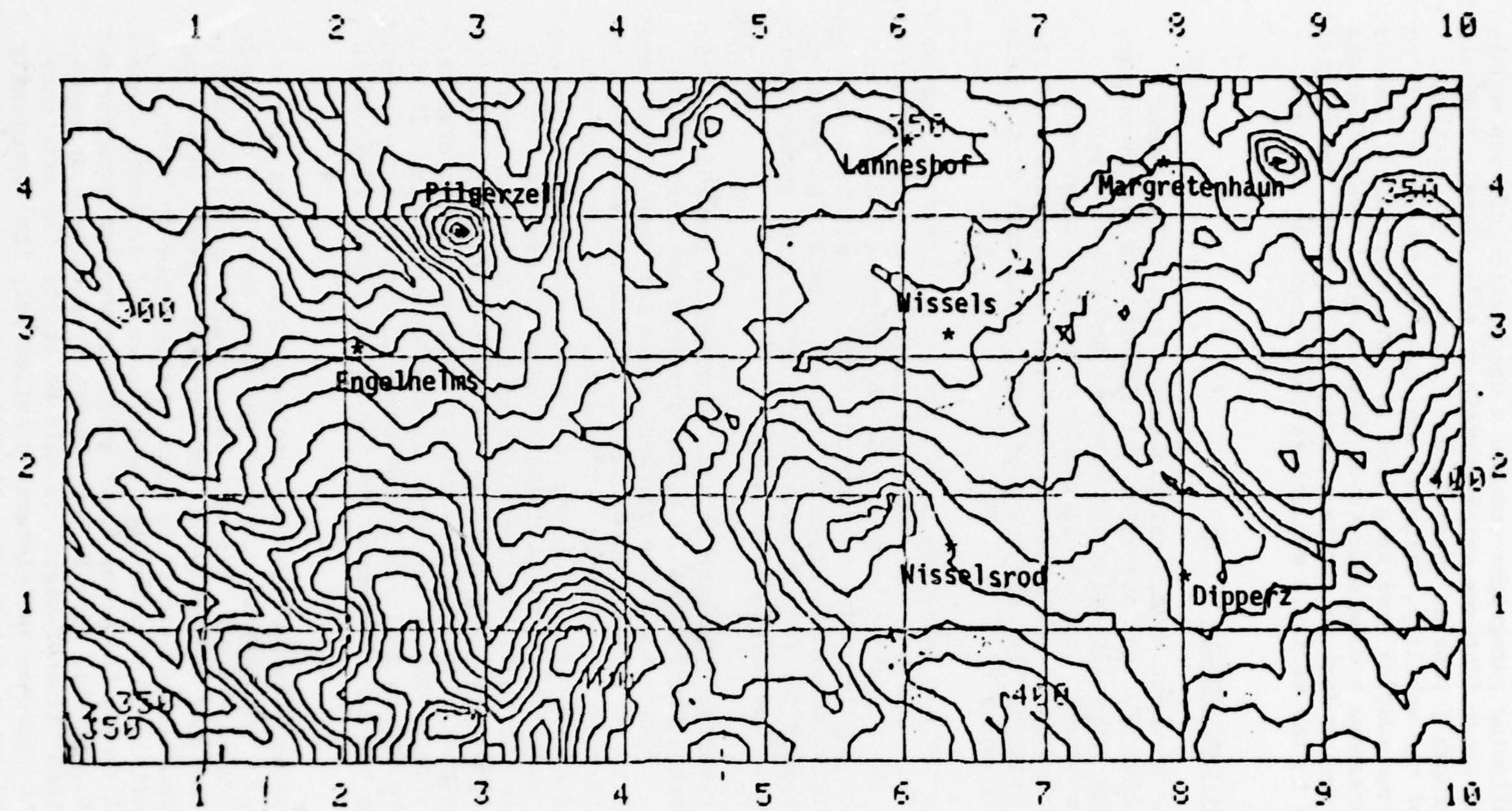

Figure 2. **Terrain data base used by the Mobility Line of Sight Module in the Battlefield Illumination Study.**

Blue Unit Type	Location No.	Red	Unit Type
Squad	1-6, 9, 12	Primary Red Force	Tank, Missile
Missile	7, 10	Diversionary Red Force	Missile
Tank	8, 11		

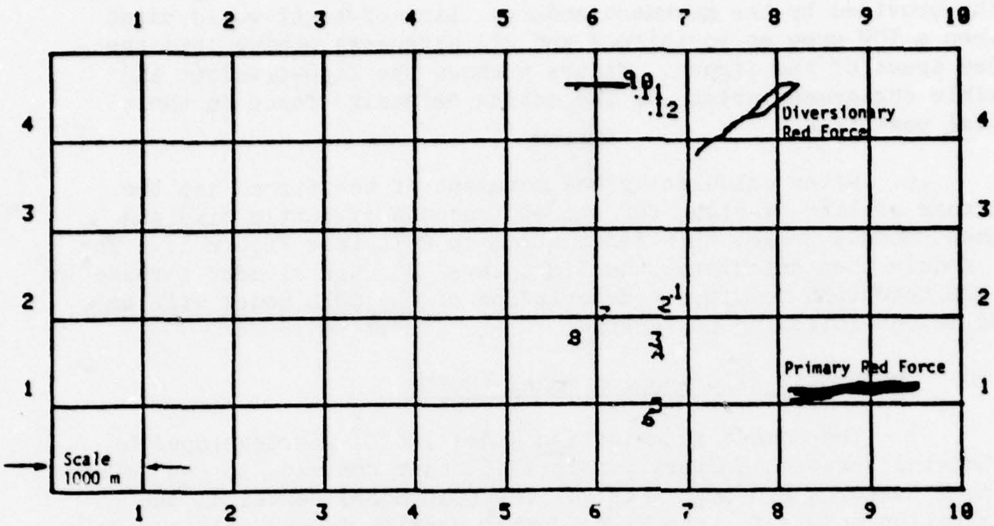

Figure 3. Tactical movement scenario for Battlefield Illumination Study. First 700 seconds of Battle.

MOVEMENT AND ILLUMINATION SCENARIO

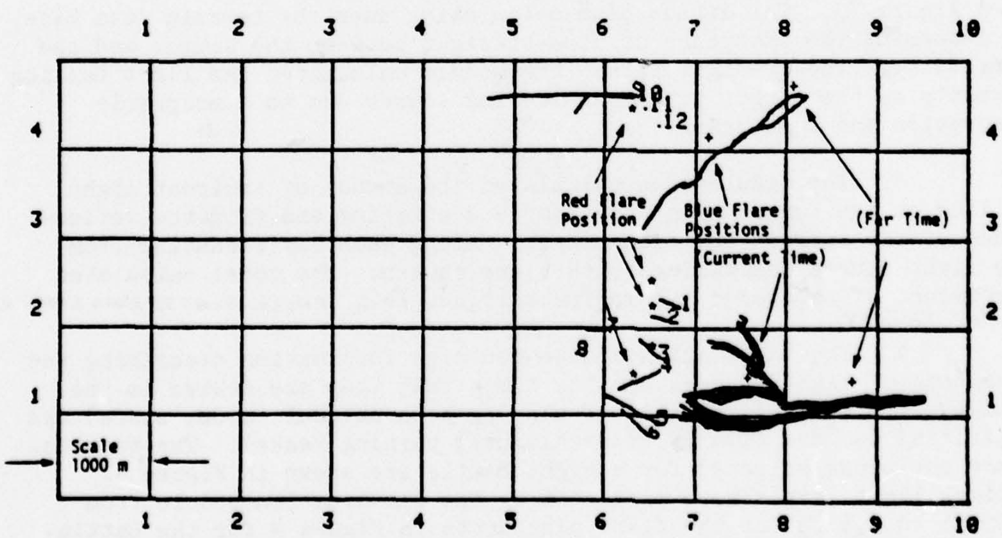

Figure 4. Tactical movement trace and flare deployment position for Battlefield Illumination Study.

on the NVL detection model that although line-of-sight may exist between opposing elements, their individual devices may limit their detection.

5. Figure 5 provides an example of the line-of-sight information provided by the movement module. Line-of-sight would exist between a TOW crew at position 7 and all attackers moving into the shaded areas of the figure. Figure 6 shows the line-of-sight and possible engagement areas for the entire defensive force in their initial positions.

6. After calculating the movement of the forces and the existence of line-of-sight for each 10 seconds of battle time and movement module passes this information to COIL (see Figure 1). The COIL module then calculates the light level at each element for use in the NVL detection module. A description of the COIL model will be found in the following paragraphs.

D. <u>The Combat Illumination Model (COIL)</u>

1. The Combat Illumination Model)COIL) was developed by the General Research Corporation in 1976 under contract to the Defense Advanced Research Projects Agency. The COIL model serves as the Illumination module for the Night Combat Model. Inputs to the module consist of environment data, describing the terrain and the atmosphere, and a tactical data base describing flare positions, their time of deployment, and the positions of all elements during the battle. Output from the model consists of a series of time phased records, which give the total illumination level at each element on the battlefield.

2. The model calculates the total ~~line~~ LIGHT at each potential target in two phases. In the first phase, light falling directly on the target from all light sources on the battlefield is calculated. (See Figure 7). The direct beam calculation uses the terrain data base to determine the existence of line-of-sight between the source and the target. If line-of-sight exists the module calculates the light falling directly on the target after considering losses due to atmospheric absorption and scattering.

3. The module then calculates the amount of indirect light falling on the target from atmospheric scattering and from the reflectance of the terrain and cloud layer. Along each ray emenating from the light source scattering centers are chosen. The model calculates the amount of scattered and indirect light FROM THESE SCATTERING CENTERS TO THE TARGET.

4. The tactical data base contains information describing the positions of light sources and the times that they are active in the battle. The model is capable of playing both natural (moon, stars) and artificial sources (flares, searchlights, burning tanks). The tactical flare positions selected for a night battle are shown in Figure 4. Typical light levels were predicted by the illumination module from 0.05 fc to 0.5 fc for the flare placements in Figure 4 for the Battlefield Illumination Study (BIS).

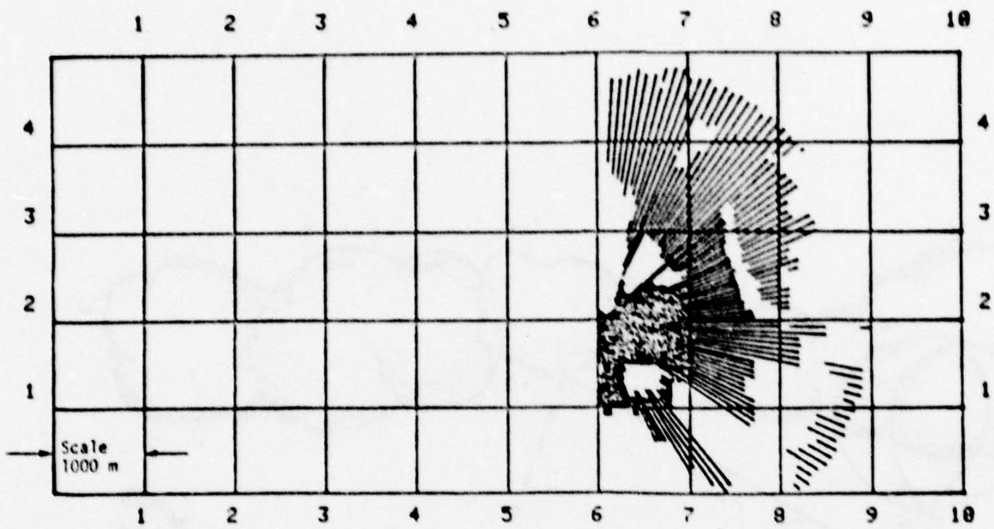

Figure 5. Physical line of sight out to a maximum range of 3000m for Tow Position 7.

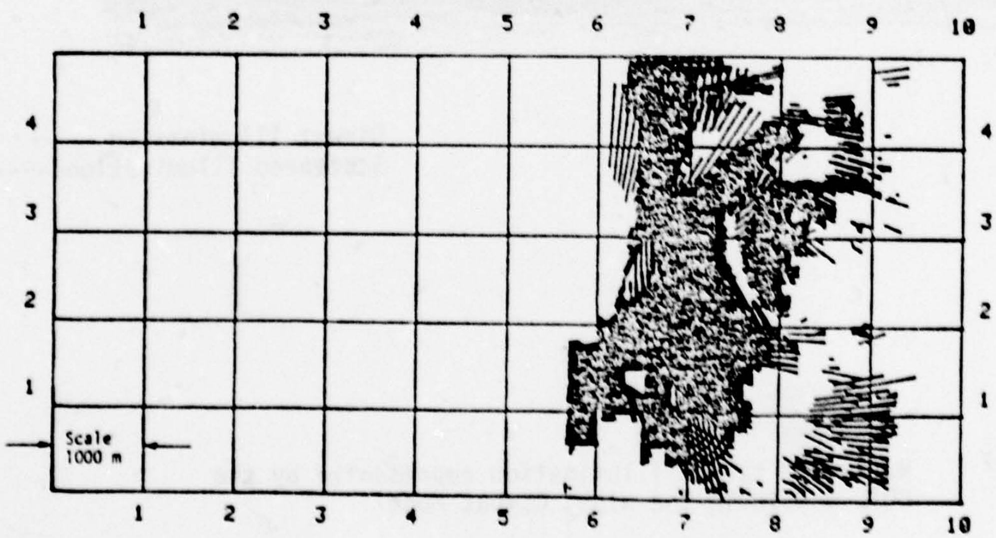

Figure 6. Physical line of sight for the entire defensive force from their initial tactical position.

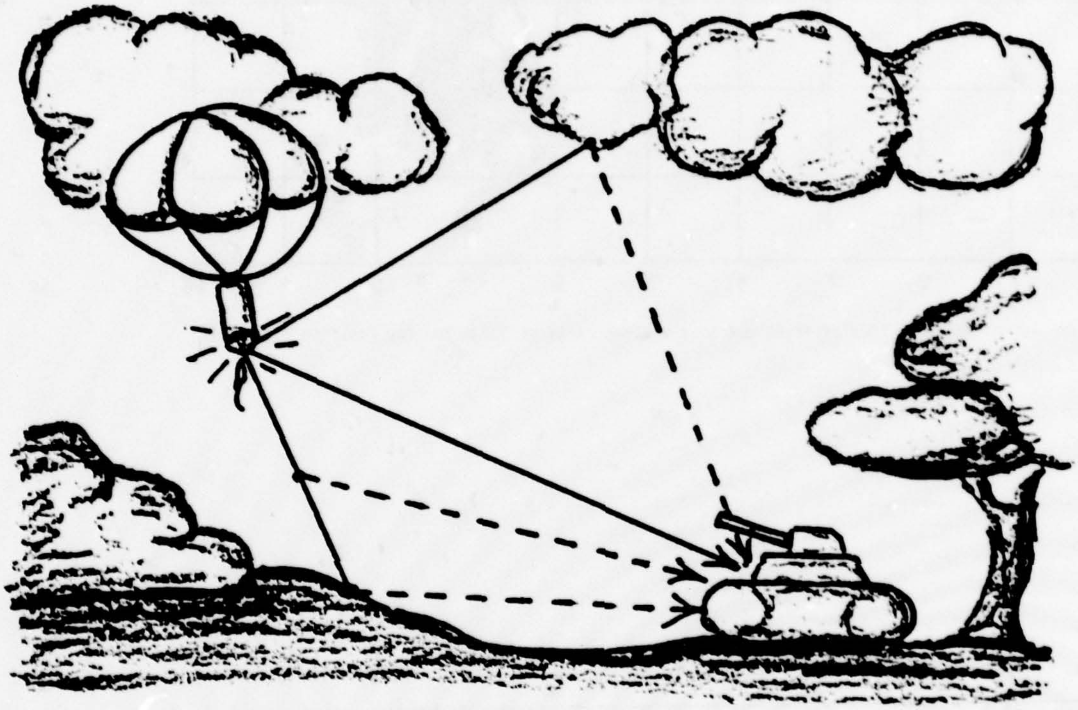

FIGURE 7. Method of target illumination represented by the COIL module in the Night Combat Model.

5. Referring again to Figure 4, the time phased movement line-of-sight records and light levels are finally passed to the AMSWAG model for calculations of force attrition. The NVL detection module has been incorporated into the AMSWAG model. The following paragraphs describe the method used by the NVL module to calculate acquisitions under various visibility conditions.

E. The Night Vision Laboratory Detection Module

1. The NVL detection module is used to calculate the probability of detection as a function of time $P_d(t)$ within AMSWAG each time line-of-sight occurs between an attacking and defending element. The target acquisition model has the following form:

$$P_d(t) = P_\infty \; P_t(m) \qquad (1)$$

where: $P_d(t)$ = the probability that a target will be detected by a searcher in t SECONDS

P_∞ = the probability that the searcher will ever detect the target, given it is in his field of view

$P_t(m)$ = the probability that the searcher will detect the target within m coverages of the search area given that he will ever detect it. Note that m is a function of time.

2. The probability P_∞ is a function of the observer's image device characteristics, that is, heat sensing, light amplifying or simple magnification. P_∞ is also a function of how well the observer can recognize the image on the device display as a target's signature. The environmental and device characteristics used by the NVL algorithm to calculate P_∞ are illustrated in Figure 8. A target moves into the field of view of an observer at range R. There is a contrast (C) or temperature difference (ΔT) between the target and its background due to their respective reflectivities or thermal properties. This intrinsic contrast or temperature difference is reduced by the intervening atmosphere. This apparent contrast or ΔT is then what the device responds to, forming an image on the display for the observer. The observer in turn responds to how he perceives the objectives within the displayed image. The probability, P_∞, represents the probability that any specific observer from an ensemble of observers will be able to detect the target under prevailing conditions.

3. An example of how the NVL detection model was used by AMSWAG in calculating detection probabilities for the Battlefield Illumination Study is shown in Figures 9 and 10. The dotted lines indicate the line-of-sight for a crew searching with a Starlight Scope from position 87. The solid area indicates the area in which BMP's and Tanks can be detected with a 50% or greater probability for a clear atmosphere and partial moonlight conditions. Comparison of Figures 9 and 5 shows that physical line-of-sight does not guarantee detection and target engagement in the Night Combat Model. Figure 10 shows the sensitivity of the model to changes in light levels. In

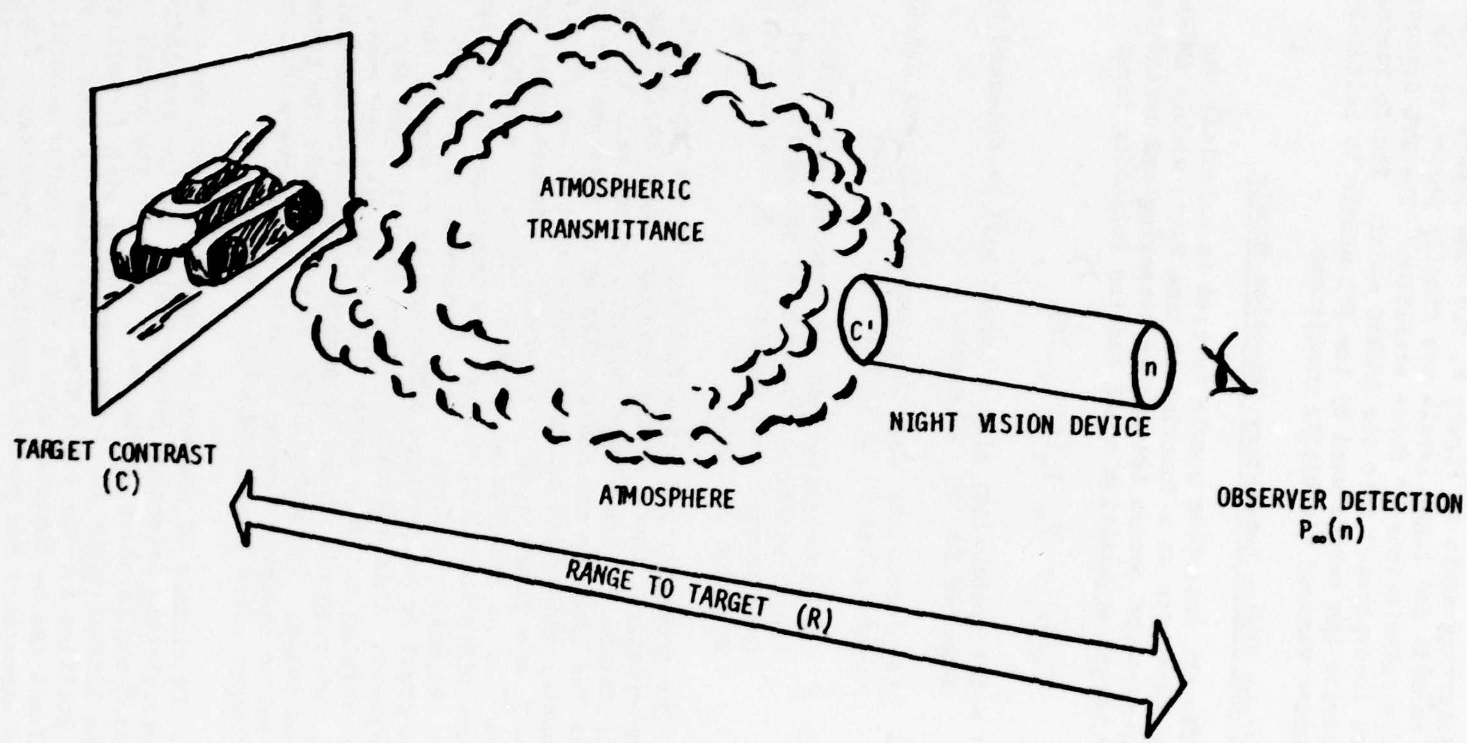

FIGURE 8. Acquisition process simulated by the NVL detection module in the Night Combat Model.

Detection (Tank or Bush) by
Starlight Scope

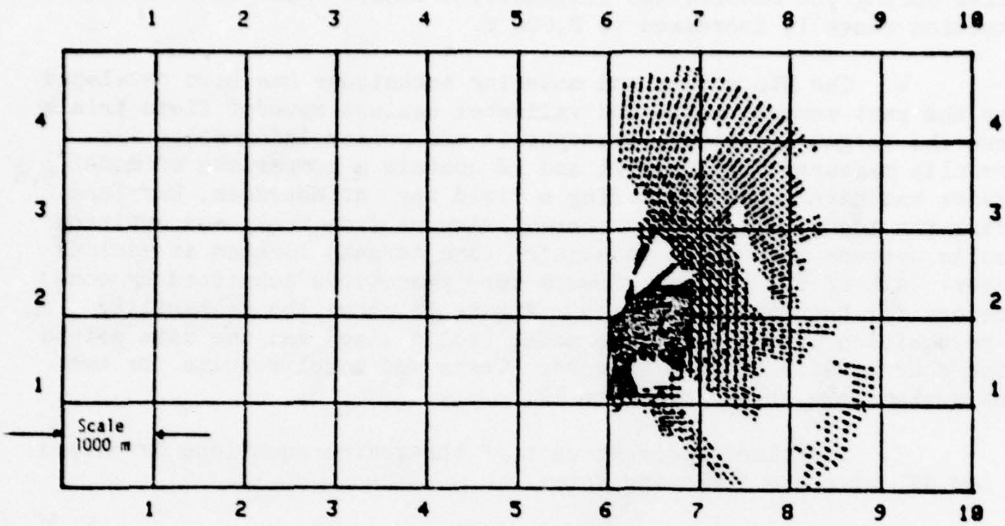

Figure 9. 50% detection fan predicted by NVL module for Starlight Scope operating at location 7. Crew searching for vehicular targets under an ambient light level of clear partial moonlight (1.0×10^{-3} ft. cdls.).

Detection (Tank or Bush) by
Starlight Scope

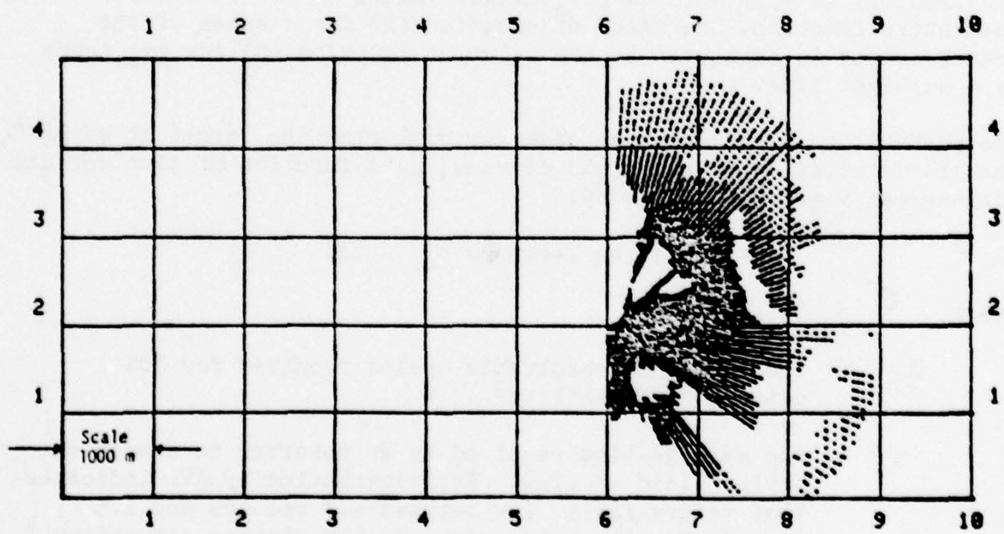

FIGURE 10. 50% detection fan predicted by NVL module for Starlight Scope operating at location 7. Crew searching vehicular targets under an ambient light level of twilight (1.0×10^{-1} ft. cdls.).

this case the Starlight Scope at position ~~8~~ 7 is operating under twilight conditions (this light level was often encountered when all flares were active during the Battlefield Illumination runs). Note that the 50% detection range is increased to 2,000 m.

4. The NVL models and modeling techniques has been developed over the past several years and validated against several field trials where the target signature, atmospheric and sensor information was carefully measured. Figures 11 and 12 contain a comparison of model results and data collected during a field test at Aberdeen, Maryland.[5,6] During the tests, crews using thermal viewers from tanks and antitank missile systems were asked to acquire tank targets located at various ranges. All of the thermal viewers were prototypes submitted by contractors for test and evaluation. Figure 11 shows the probability of recognition predicted by the model (solid line) and the data points using four missile thermal viewers. Tests and model results for two tank systems are shown in Figure 12.

5. The time dependent part of the search equations developed by ~~the~~ NVL have the following form:

$$P_d(m) = (1-(1-P_s(t_o))^m) \qquad (2)$$

where: $P_s(t_o)$ = the probability of finding the target within the field of view of the device within time t_o.

m = the number of times the observer has covered the entire search fan~~s~~.

This equation assumed that the observer covers his search sector in an ordered fashion with his device's field of view.

Equation (2) is only defined for integer values of m. To create the entire function, the value of equation (2) for r scans of the search sector is connected to the value of equation (2) for <u>r</u>+1 scans by a straight line.

The probability $P_s(t_o)$ that an observer will find the target at range R, when it is within his field of view, as a function of time for all but thermal viewers is given by:

$$P_s(t_o) = 1-\exp(-\sigma t_o) \qquad (3)$$

Where: $\sigma = 8N_{50}/N$

N_{50} = the number of resolvable cycles required for 50% detection probability[3]

t_o = the average time required by an observer to search one device field of view. Experimentation by NVL indicates that values for t_o lie between 1.7 seconds and 1.5 seconds for thermal devices in low clutter situations.[4] A value of 1.7 seconds was used in the Battlefield Illumination Study.

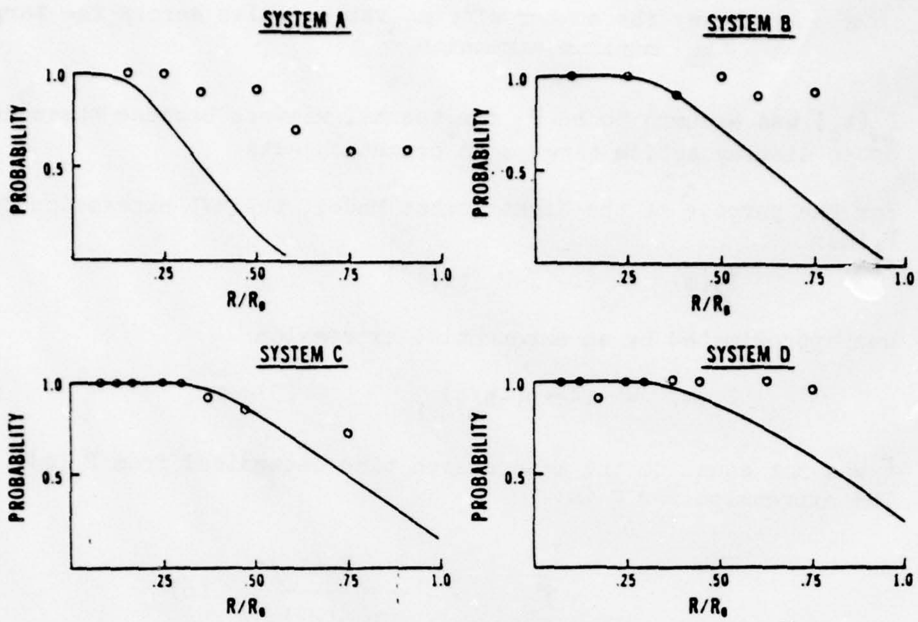

Figure 11. Comparison of NVL detection model and field test data on the ability of crews, using four thermal missile viewers, to recognize a tank.

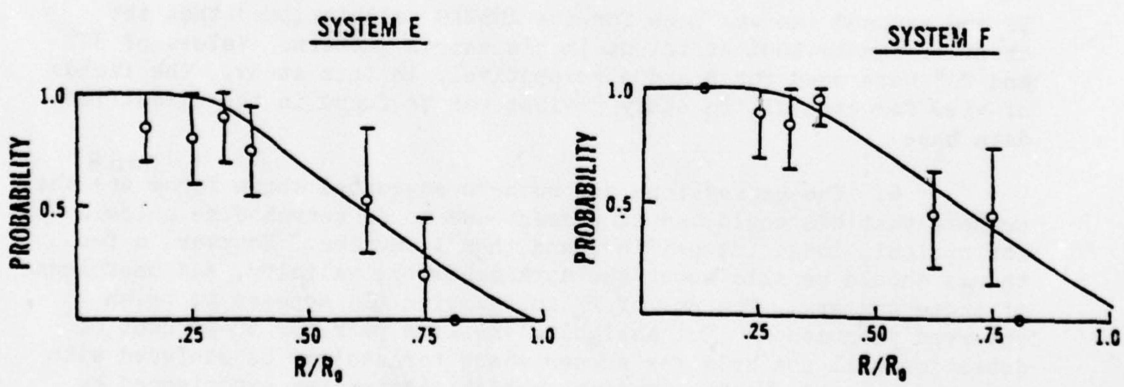

Figure 12. Comparison of NVL detection model and field test data on the ability of crews to use two tank thermal viewers to recognize a tank target.

N = the number of resolvable cycles across the target's minimum dimension.[3]

$P_s(t_o)$ was assumed to be P_∞ for thermal viewers because these devices often display active targets as bright objects.

For the purpose of the Night Combat Model, the NVL expression for $P_d(m)$:

$$P_d(m) = (1-(1-P_s(t_o))^m) \qquad (4)$$

was approximated by an exponential expression:

$$P_t(m) = 1-\exp(-t/\bar{t}) \qquad (5)$$

$\bar{t}$ was not equal to the mean search time determined from $P_t(m)$. The expression for $\bar{t}$ is:

$$\bar{t} = t_o \frac{\theta\,\phi}{f_2} \quad \frac{2 - P_s(t_o)}{P_s\,(t_o)} \qquad (6)$$

Where: θ, ϕ = the horizontal and vertical search fields in degrees

f_2 = the device field of view squared in degrees

Note that the time required to scan a search field once is:

$$t_s = t_o \frac{\theta\,\phi}{f_2}$$

If one assumed (as was done for the AMSWAG calculations) that the observer can be 100% efficient in his search pattern. Values of 30° and 20° were used for θ and ϕ respectively in this study. The fields of view for each of the study devices can be found in the classified data base.

6. The expressions and numbers suggested above for SEARCH are the numbers that NVL would use at present ~~use~~ to do search time calculations for optical, image intensifier, and themal devices. However, a few things should be said about the applicability, validity, and usefulness of these numbers. The use of P_∞ in equation (1) appears to be an observed phenomenon. But assigning one line pair for 50 percent of detection will not hold for scenes where targets may be confused with other background objects (medium or high clutter) as experienced by NVL at Fort Huachuca, New Mexico. In this experiment two resolvable cycles were required for 50 percent detection.

NVL is continuing to conduct experiments in attempts to find relationships between background target complexity and the variables $\bar{t}$, f, and the efficiency with which one can search an area with a device.

F. The AMSWAG Module

The AMSWAG module is basically the AMSWAG model (Reference 7) with the previously described representation of the NVL acquisition model incorporated as a subroutine which is exercised for each potential firer-target combination when line-of-sight exists.

The AMSWAG model is a time sequenced (10 second intervals), force-on-force, battalion level, high resolution combat simulation. This Lanchester theory based model is deterministic (expected value) in nature and depicts a deployed attacker maneuvering on fixed routes of advance toward the defending force. The AMSWAG model results are presented in the form of sequential killer-victim scoreboards, ammunition expenditures, exchange ratios and percent losses throughout the engagement.

Several modifications have been implemented since the referenced publication, the primary changes being in the area of target acquisition. For indirect fire acquisition, the artillery subroutine previously assessed damage to a unit if it occupied one of several preselected grid squares. Artillery is now allocated to a target per the above scheme only during the PREP (preparatory) fire stages; during the assault phases of combat, the allocation to a target is in accordance with the acquisition accumulated by units designated as forward observers (FO's). Thus, line-of-sight governs the target effect of artillery instead of the chance occupancy of a particular grid square. Direct fire weapons have two types of acquisition based on firing and nonfiring targets.

The nonfiring acquisition, visual search, employs the NVL methodology. An NVL generated data base, in table form, was employed in AMSAA's recently completed efforts (Reference 8, 9) for the Harry Diamond Laboratory, the Night Vision Net Technical Assessment (NVNTA). This first use of the NVL model was limited to three specific uniform light levels corresponding in general to day, moon and star conditions. The AMSWAG module now in use is much more flexible with respect to the conditions which can be addressed. Furthermore, it is easily managed with respect to the device characteristics and conditions for which data exists and, most important, readily adaptable to merging new data for additional devices or inserting improved processes for the previously estimated parameters.

By combining the NVL acquisition model with the elements of the DYNTACS mobility preprocessor and the COIL model into the overall AMSWAG methodology, a dynamic treatment of variable acquisition processes has been achieved.

III. NIGHT COMBAT MODEL RESULTS

The Battlefield Illumination Study was recently completed by the authors of this paper and a brief description of the scenario, results and conclusions are provided herein as a demonstration of the model capabilities.

A. Scenario

The battle occurs between a Red tank battalion and a Blue mechanized Infantry Company. The battle terrain is located in the Fulda Gap area approximately 5 km East of Fulda. The Red force consists of 12 tanks and 21 missile launching APC's. The Blue force has 4 tanks, 5 missile launching vehicles and 9 squads with short range missile capabilities. The force locations and routes are given on Figures 3 and 4.

The Blue forces believe that Red's objective is to gain control of the area around the villages of Pilgerzell and Engelhelms in preparation for a morning attack on the Fulda railyards. In the event of an overpowering Red force, Blue has selected secondary positions. The Blue missile vehicles will pull back when Red approaches within 1500 meters, the squads will remain until a 500 meter separation exists and then move.

The Red force has been instructed to deploy in platoons (2 tanks and 3 APCs), overrun and occupy the initial position of any Blue opposition they encounter. Red is using the primary and diversionary forces as shown on Figure 3.

Due to the cloudy, overcast conditions (visibility range at 7 km) and very low ambient light levels, both forces have made preparations for the use of "on-call" artillery delivered flare illumination. Red has allocated enough artillery to continuously illuminate 10 positions over suspected defensive locations. Blue can maintain 4 locations over the approach routes.

B. Case Considerations

For a particular level of fire control, lethality and vulnerability for both force cases were run with Blue using optical, image intensifier and thermal devices while the Red force used image intensifier and thermal devices. The next section will show the actual combinations considered. The cases were run with Blue employing standard 155 flares, modified flares to increase light level (1/2 burst height and twice the candle power) and using an IR light source.

C. Results

Figure 13 provides a brief summary of the end of game results. End of game was considered to be the time at which Red occupied the Blue force's initial positions.

The primary observations for the purposes of this presentation are:

1. Device improvements for the Blue force permitted longer opening range engagements.

2. The longer range openings, lessens the Red 3.7: 1 vehicle force ratio advantage and strengthens the Blue fire control and exposure advantage.

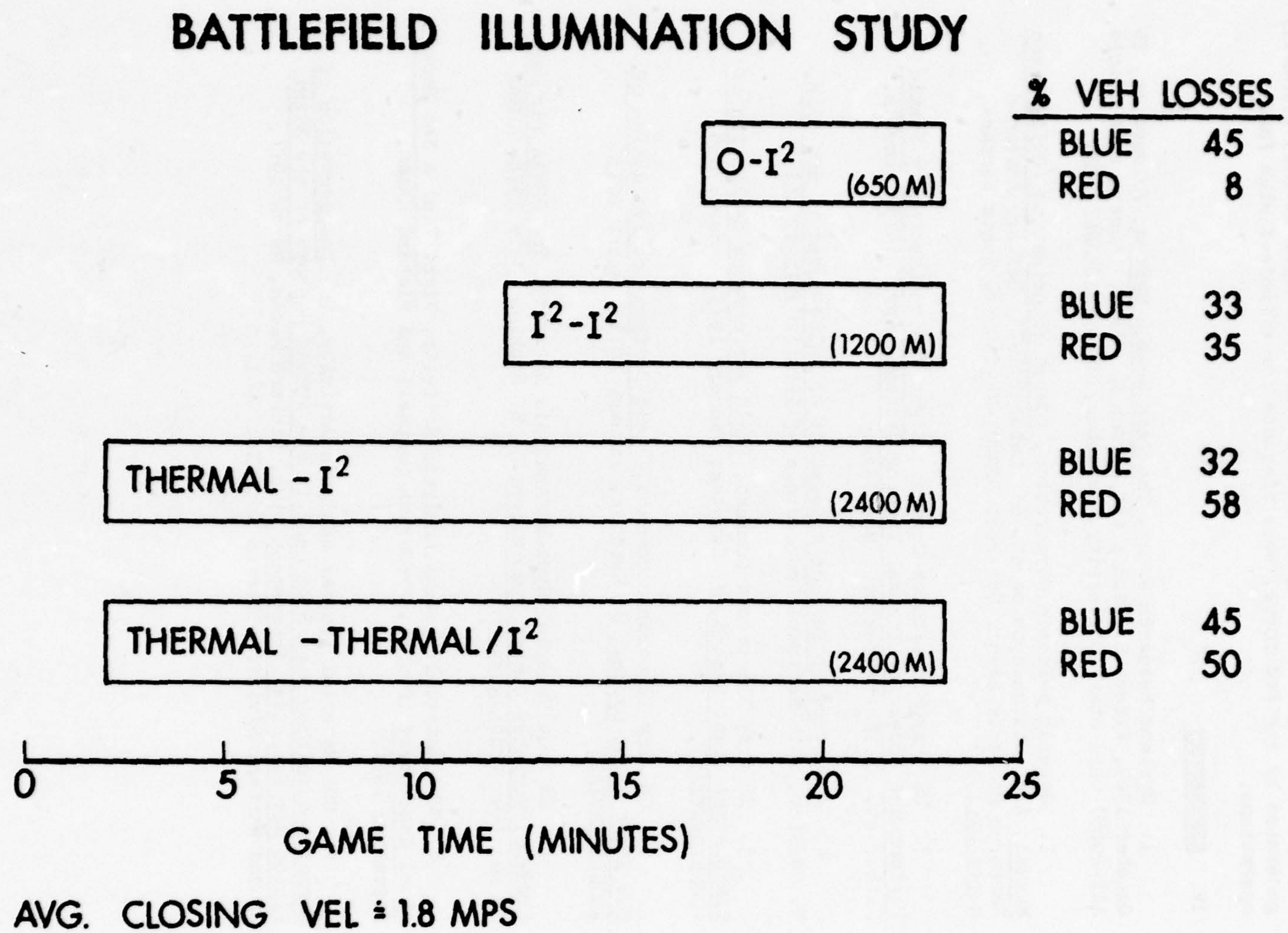

FIGURE 13. SAMPLE END OF GAME RESULTS

The changes considered for the Blue flares did not have any significant effect on the game results since the light levels, primarily generated by the Red force, were adequate for efficient Blue force operations.

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TITLE: A Smoke Effectiveness Model

AUTHOR: Mr. George Stiles (USA Materiel Systems Analysis Activity)

ABSTRACT: A simple model of a smoke screen has been developed to predict the effect of the smoke on the effectiveness of electro-optical systems. The present model is restricted to smoke generating source which have a constant output. Transmittance of the smoke is computed but other effects such as scattering of sunlight and thermal radiation are ignored. Some input data is given for use in the model. An example is discussed to illustrate some features of the model.

TITLE: A Smoke Effectiveness Model

AUTHOR: Mr. George Stiles (USA Materiel Systems Analysis Activity)

Recommended quantities of smoke munitions to screen against visual observations have been obtained with the aid of large computer models and extensive field tests. For certain applications, it would be useful to have a simple model of a smoke screen which can be used on a small electronic calculator. Applications could include setting up static munitions for field tests and predicting the performance of electro-optical systems through tactically deployed smoke screens.

DERIVATION OF THE TRANSMITTANCE FORMULA

In order to meet the requirements for simplicity, the model must be restricted by a number of constraints, as shown in Figure 1. We assume a smoke cloud with the simplified shape of Figure 2.

By making these simplifications it can be shown that the optical transmittance through the cloud in a horizontal direction is a simple exponential function of distance from the smoke source as shown in Figure 3.

Attenuation coefficients measured in the laboratory are shown in Figure 4. It is of interest to note the large coefficients of phosphorous smokes compared to HC and fog oil at 10.6 micrometers and in the 8-12 micrometer range.

Computed values of the smoke production rates for a few smoke munitions are shown in Figure 5. The values of smoke production rate include factors to account for the mass of the water vapor which condenses to form the smoke droplets, the efficiency of the smoke generation process, and the reduced effectiveness of white phosphorous due to the formation of a vertical pillar. The 155mm shell and the 2.75 inch rocket are to be issued beginning in 1980 and 1981 respectively. The others are available for issue.

Values of the smoke cloud rise angle are shown in Figure 6. The three values given were obtained from field test data.

RESULTS

Computed values of optical transmittance at three distances downwind from a single Mark 4 rocket are shown in Figure 7. Two lessons can be learned from this results:

1. Transmittance varies over a wide range in a comparatively short distanee downwind. This could be a source of difficulty in comparing field measurements with calculations.

2. A suitable smoke screen can be formed by placing munitions in a line separated by the distance which gives the desired upper value of transmittance. For instance, a line of Mark 4 warheads separated

by 15 meter intervals should produce a smoke screen with a transmittance everywhere less than .01 under favorable meteorological conditions.

Figure 8 shows a typical arrangement for a field test with a single source of smoke producing a smoke screen with width W, height H, and transmittance T. The smoke source must be placed far enough upwind that the upper edge of the smoke will reach height H. The location of the source is thus determined by height H and the angle a which is determined by meteorological conditions.

In Figure 9 we show an example in which the Mark 4 rocket warhead produces a smoke of transmittance .1 over a width of 50 meters and a height of 5 meters. If the rise angle is 11 degrees (neutral conditions), tan a equals 0.2 and the smoke source must be located 25 meters upwind from the test area. In the upper drawing we see that a single M4 rocket warhead produces a smoke cloud which has a transmittance of .01 at 30 meters downwind. This gives a coverage of only 5 meters in the test area. In the middle drawing two sources located together produces a smoke cloud to 60 meters downwind. In the lower drawing three warheads produce a smoke cloud to 90 meters and so meet the requirements for 50 meters width.

Other requirements may necessitate more complicated solutions such as munitions located at several sites.

Smoke screens specified only by transmittance may further degrade electro-optical systems by scattering solar radiation into the optical path and by radiating thermal energy derived from chemical reactions.

SUMMARY

The model of a smoke screen described here may be used to obtain estimates of munition requirements for particular applications. When more accuracy is required, a more sophisticated model must be used.

CONSTRAINTS ON MODEL

- SMOKE EMITTED AT CONSTANT RATE
- CONSTANT WIND
- RECTANGULAR CLOUD CROSS-SECTION
- UNIFORM SMOKE CONCENTRATION OVER A CROSS-SECTION
- CLOUD LOWER EDGE ON GROUND
- CLOUD UPPER EDGE AT ANGLE α
- SMOKE PROPERTIES CONSTANT IN TIME
- NO SCATTERING IS COMPUTED

Figure 1

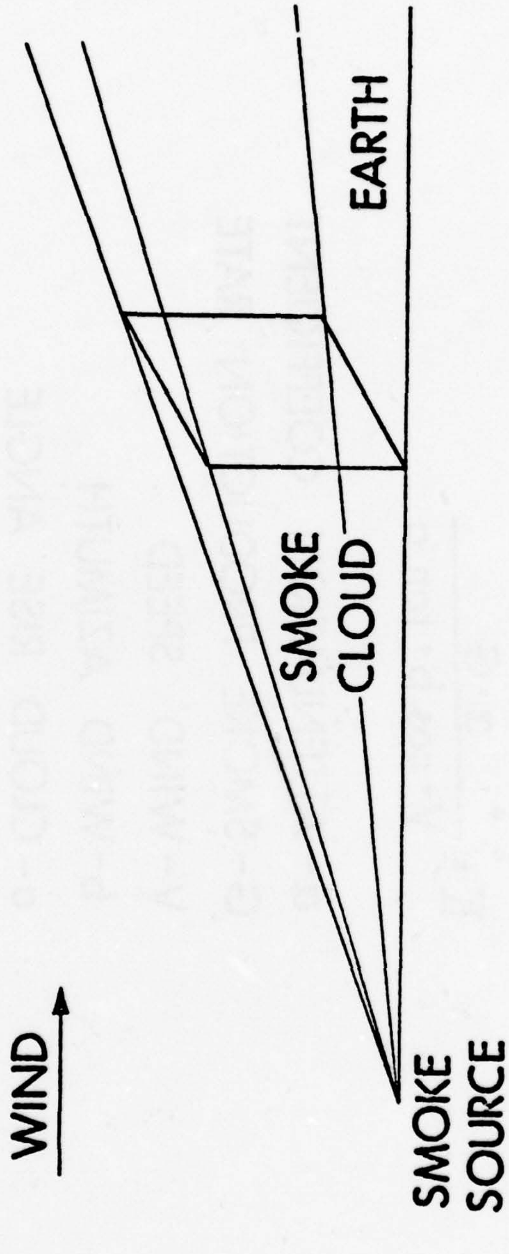

Figure 2

$$T = \exp\left(\mathbb{K}/X\right)$$

$$\mathbb{K} = -\frac{\alpha \cdot G}{V \cdot \cos b \cdot \tan a}$$

α – ATTENUATION COEFFICIENT

G – SMOKE PRODUCTION RATE

V – WIND SPEED

b – WIND AZIMUTH

a – CLOUD RISE ANGLE

Figure 3

ATTENUATION COEFFICIENTS (α)

WAVE-LENGTH	PHOSPHORUS WP/RP/PWP	HEXACHLOROETHANE HC	FOG OIL	FS
VISUAL	3.36	2.38	3.20	3.85
1.06	2.67	NA	4.03	2.87
3.39	.43	.38	1.08	.37
10.6	.49	.067	.034	.15
3-5	.25	.15	.45	.15
8-12	.28	.061	.085	.24

UNIT: SQUARE METERS PER GRAM.

Figure 4

SMOKE PRODUCTION RATE (G)

SMOKE SOURCE	PRODUCTION RATE GRAMS / SECOND	BURN TIME MINUTES
SMOKE POT MS (HC)	44	5.0
MORTAR, 4.2 INCH (WP)	48	0.5
ROCKET 5 INCH MARK 4 (PWP)	106	5.5
ROCKET 2.75 INCH (WP-WICK)	22	5.0
HOWITZER 155 MM (WP-WICK)	115	5.0

Figure 5

SMOKE CLOUD RISE ANGLE (a)

FIELD CONDITIONS	SKY	TIME OF DAY	tan a
FAVORABLE	HEAVILY OVERCAST	NIGHT OR EARLY MORNING	6°
AVERAGE	PARTLY OVERCAST	MID-MORNING OR LATE AFTERNOON	11°
UNFAVORABLE	CLEAR	11 a.m. TO 4 p.m.	19°

Figure 6

SMOKE TRANSMITTANCE VS DISTANCE

MARK 4 (ZUNI)

DISTANCE FROM MUNITION	OPTICAL TRANSMITTANCE
10 M	.001
15	.01
30	.1

Figure 7

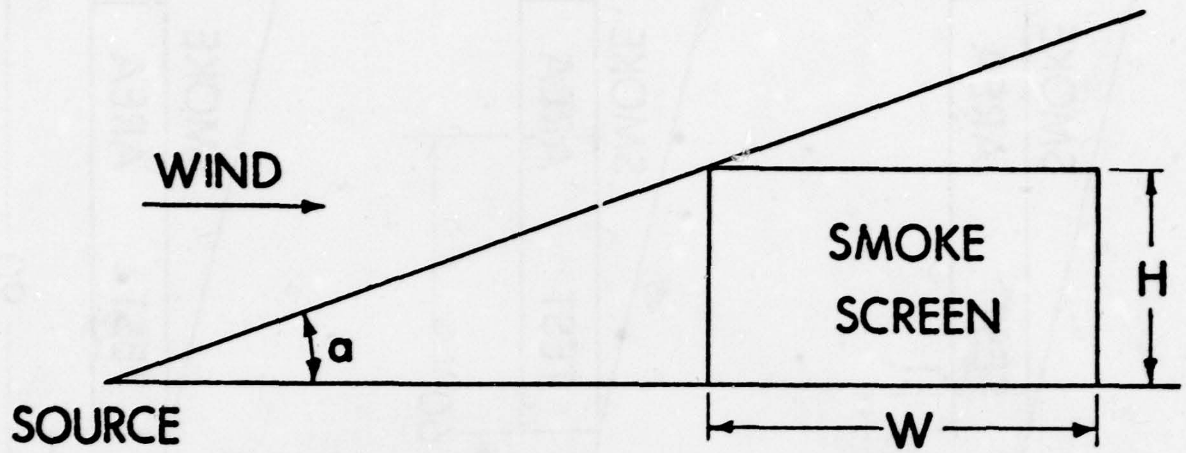

Figure 8

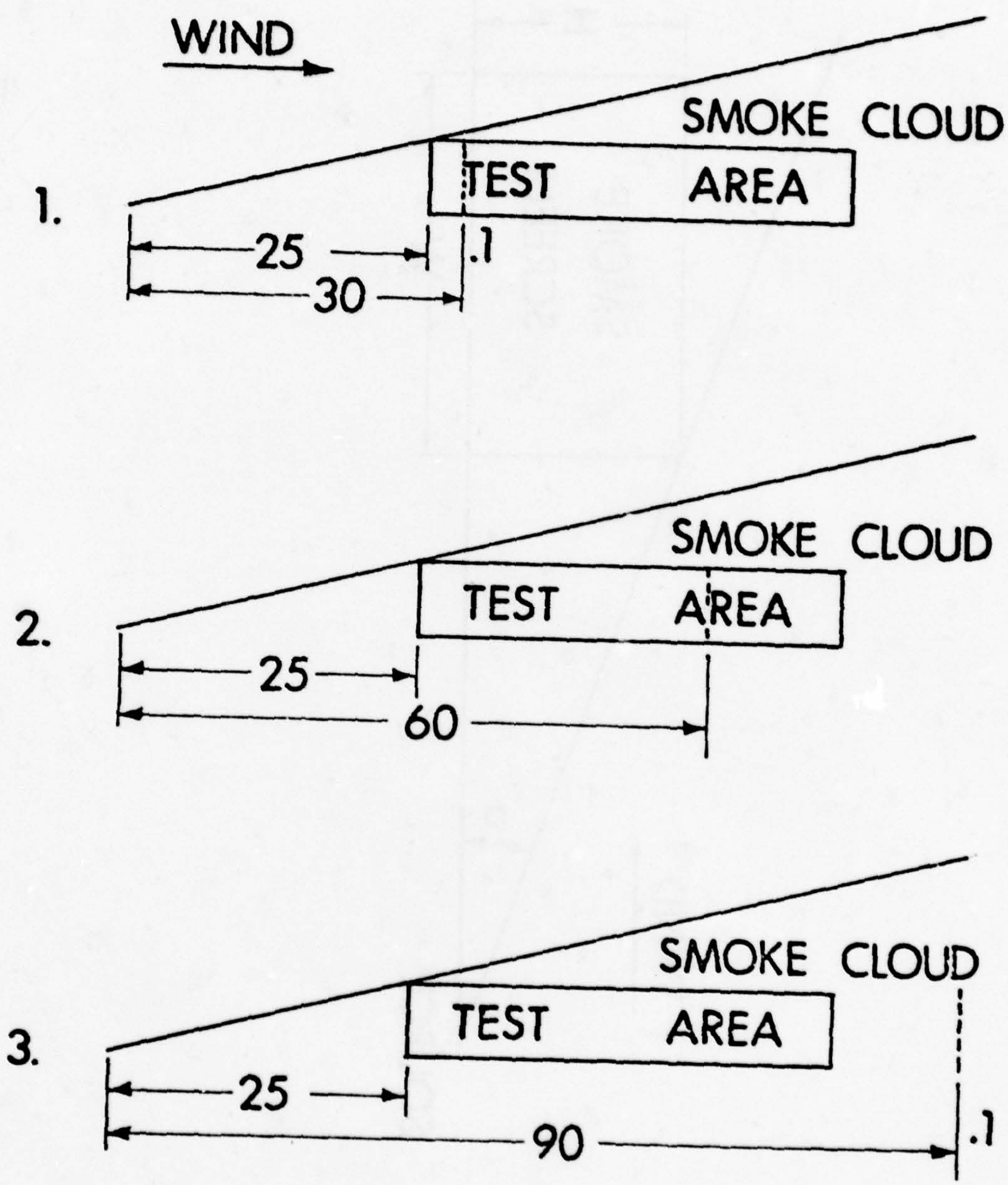
WIND
SMOKE CLOUD
TEST AREA
1.
25
30
.1
SMOKE CLOUD
TEST AREA
2.
25
60
SMOKE CLOUD
TEST AREA
3.
25
90
.1

Figure 9

COMBAT ANALYSIS

Mr. Bruce W. Fowler and Mr. Donald R. Peterson
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Mr. O. Fred Kezer
USAMERADCOM

The Impact of Smoke and Battlefield Obscurants on Tactical Weapons Systems

Force on Force (FOF) modeling has become a common DOD tool for performing preliminary tactics and doctrine development, for analyzing cost and operational effectiveness, and for analyzing the usability of research projects. A major shortcoming of current FOF models is that they do not include the effects of Battlefield Aerosols and Obscurants (BAO) in arealistic manner. In view of the impact of BAO on SMART weapons systems, a renewed emphasis must be placed on evaluating the position of the field commander under these conditions. To function as a highly effective, fully integrated military unit, prior information on the level of degradation that can be expected under these situations is needed.

In short, what price will be imposed upon a military force with SMART weapons by defensive or offensive use of BAO?

The emphasis of this presentation will be placed upon demonstrating the utility and effectiveness of incorporating smoke effects into FOF models in a usable, reliable manner.

Historically, the military use of the visible region predates recorded history, while the use of the Infrared (IR) and the radio (RF) dates from the late 1930's. The millimeter (mm) and the submillimeter (sub mm) regions have not yet been used in a military sense, currently being regions of R&D interest. The use of passive countermeasures (CMs) has followed the deployment of each region. In the visible, smoke has been used tactically since at least the time of Gustovas Adolphus. (1) The use of IR and RF CMs was common in the 1940's, in the latter case being referred to as chaff. These CMs have all been based on one or more of three physical phenomena: absorption, scattering, and emission. The discussion in this paper will be primarily concerned with the first two phenomena, collectively called extinction, and only coincidentally with the third when it occurs as a natural result of implementation.

The effects of BAO on military operation are important because the current and projected arsenals of modern weapons systems are impregnated with subsystems that make use of several wavelength regions of transverse electromagnetic radiation, commonly called light. This radiation is usually discussed in terms of wavelength regions that are loosely correlated with the equipment necessary for generation and/or detection of the radiation. These regions, in order of increasing wavelength, are the ultraviolet (UV), the visible, the IR, the sub mm, the mm, and the RF. Several of these regions are in turn subdivided, such as the IR and RF. Because the UV and RF have until recently been used primarily for Air

Defense and the mm and sub mm technologies are still youthful, this discussion will be limited to implications in the visible and IR regions, although much of the discussion may be scaled into the other regions. The traditional deliberate CM in these regions has been smoke, perhaps because of its presence on the battlefield originally as a coincidence of gunpowder use.(2) Other, coincidental orscurants include dust, fog, haze, rain, snow, and the molecular constituents of the atmosphere, both natural and artificial in origin. These obscurants fall into two catagories, molecular and aerosol. (3) The molecular phenomenology is well understood and enjoys a highly accurate level of measurement and modeling. (4)

Aerosols fall into one or both of two catagories, being either spherical or not spherical in shape. Liquid aerosols such as fog and many smokes are generally spherical, while rain is often almost spherical, being sufficiently larg- to be deformend by gravity and aerodynamic drag. Solid aerosols such as dust, snow, and atmospheric haze are generally not spherical, although it has been traditionally assumed that these aerosols may be considered as spherical in sufficiently large, randomly oriented numbers. (5) The extinction properties of a single spherical particle have been elucidated by Mie (6) and those of a group of independent spherical particles have been developed by Deirmendjian. (7) The properties of non spherical particles are currently under investigation at several laboratories. (8)

Given the extinction properties of the aerosol media, it is necessary to know the transport properties of the appropriate wavelength light through the media. This is an area that has been and is still being extensively studied both experimentally (9) and theoretically. (10) One of the current problems hampering these investigations is the correlation of the experimental data with the theoretical models. This difficulty arises not only from the complexity of the models but also from the incompleteness of the data. While it is not possible at this time to validate the propagation models with any high degree of satisfaction, there is adequate experimental data to construct interim parametric models for use in FOF models. This alternative will be shown to be consistent with the needs of the systems analyst.

Once the light transport properties of the aerosol-atmosphere media have been elucidated, it remains to model the sensor-target-background system. This modeling depends on the sensor system to be considered. If a passive imaging system such as the human eye, near IR TV system, or a FLIRis to be analyzed, both the intensity and the contrast of the target and the background must be considered. (11) If the performance of a laser designator is to be analyzed, the beam spread, spillover, and pulse stretching must be considered. (12) Fortunately, accurate sensor models for many sensors already exist that may be used for this type of analysis. (13)

The implementation of smoke effects into FOF models is complicated by two factors:

> Existing FOF models are long, requiring extensive computer memory, run time, and analysis effort.
>
> Existing smoke models are also long, requiring extensive computer memory and run time, and are inadequately supported by experimental data.

Concolidation of these models without forethought results in a model of such complexity and size as to preclude its use as a viable, relevant tool for the systems analyst.

The existing FOF models are extremely large in terms of computer memory requirements and execute in greater than real time. Thus the inclusion of a BAO capability within the FOF model should significantly increase neither the memory requir-ments nor the run time. The existing Mie-Deirmendjian codes require several octal decades of core and several seconds of run time per aerosol. Existing radiation transport codes either require sufficient core to preclude their execution on most computers or require excessive run time. These radiation transport code also admit changes only in the concentration of aerosol in the media and not changes in the micro-structure of the aerosol. Even realistic codes modeling the concentration changes in time and space are not small and require run time that is proportional to their accuracy. While this flexibility could be incorporated into the smaller, longer running radiation transport codes at the expense of increasing the run time by at least one order of magnitude, it has not been seriously attempted to date. As a matter of speculation, it will probably be necessary to incorporate this flexibility to reconcile the models with the experimental data.

Even with the existing Mie-Deirmendjian codes, the concentration codes, the radiation transport codes, and the sensor codes, brute force addition of smoke capability to the FOF models would result in an increase of core and run time requirements of such extent as to preclude any extensive or useful analysis. Thus, BAO capability must be implemented in a manner that does not require either extensive additional core or run time.

This situation may be mitigated by recognition of the basic accuracy limitations of the FOF models and the necessary smoke effects observables for characterization of detector/sensor performance. The approximations extant in the FOF models allow only certain munitions, ranges and meteorological conditions to be considered important, while the types of smoke effects that must be considered are limited to those that alter the performance of the deployed (present and projected) sensors on time scales consistent with the FOF models.

The overall alteration of a weapons systems' performance by all the smoke effects relevant to the detector/sensor subsystem may be quantified as a parametric function of the known physical properties expressed in the form of class variables. Specifically, the function $P(j, R, X, \Delta\lambda, l, n, \{M\}, \{T\}, \{B\}, t, t')$ is the relative performance of the detector/sensor j (e.g. FLIR) of wavelength band $\Delta\lambda$(e.g. 8-12μ) of a weapons system operating against a target of type l (e.g. M-60) at position R (e.g. 3 km N) and time t (e.g. now) against a background {B} (e.g. heavy woods) across terrain {T} (e.g. rolling grassy hills) with meteorology {M} (e.g. Pasquil catagory F, etc.) in the presence of a smoke munition of type n (e.g. 155mm HC) deployed at position X (e.g. 10 m in front of target) at time t' (e.g. now minus 5 sec.)

This function may be further parametrized, if necessary, on the basis of the operational mode of the sensor. This necessity may be seen by considering the special case of a FLIR being used to search for a tank target which has been equipped with an onboard selfprotective smoke system. If the tank has not been detected, but is in the FLIR FOV

when the smoke is deployed, there is some high probability of the FLIR operator detecting the smoke and thereby being cued to the probable presence of a target. In this case, the detection of the tank after the smoke clears will probably occur sooner than if no smoke had been deployed. If the tank had been detected prior to smoke deployment, and is being tracked, there is a probability that track will be lost when the smoke is deployed, and the target must be redetected and tracked when the smoke clears.

The use of the performance function P may be seen in the latter case described above. If the probability of maintaining track on the target in the ansence of smoke (but all other conditions being the same) is PT(clear) or the probability of recognition is PR(clear), then PT(smoke) and PR(smoke) are equal to PT(clear) P and PR(clear) P, respectively.

These performance functions may be developed from the smoke models or in a more limited sense, from experimental data. The latter method has the advantage that the data is trustworthy, but has the disadvantage that the data are invariable and limited in scope. The former method offers greater flexibility, allowing performance estimations for smokes and sensors/detectors that have not been experimentally tested, but has the current disadvantage of being poorly correlated with the existing experimental data. Since the primary purpose of this paper is a discussion of the method of simulating smoke in FOF models, further, detailed descriptions of the generation of the exact performance functions is not germane. Therefore, this description will be left to other papers and it will be assumed that the perofrmance functions can (and have) been generated, and the further discussion can be primarily concerned with the general form of the performance functions and their use.

If a generic far IR FLIR is considered, two representative performance functions (shown only as time variable) are shown in Figures (1) and (2). As has been previously indicated, several of the variables of the performance function are class variables; the performance function is insensitive to rather extreme variation in these variables; indeed, this is the whole basis of the parametrization. Figure (1) shows the general form of the performance function when pyrotechnic smoke is deployed between the target and the FLIR at some nominal range, meteorology, terrain, etc. when the smoke is deployed either along the line of sight to the target or to the left of the line of sight (relative to the FLIR) but still in the FOV. The deployment time of the smoke is marked. It may be seen that before the smoke is deployed, the performance of the FLIR is not effected by this smoke munition. When the smoke is deployed, the performance is degraded, in this case to zero. The performance remains zero until smoke combustion is complete and if the smoke is dense enough, it remains zero beyond the end of combustion. If the smoke is not completely formed before combustion is complete, the performance function may rise above zero when combustion is complete but fall again as the smoke completes its formation. After the smoke has completed combustion and formation, it begins to diffuse and dissipate, and the performance curve rises back up to one. In general, the time scales envolved are primarily dependent on the munition type (ergo size and smoke material,) placement, and local meteorology. If multiple rounds

of the munition are used, the overall effect is approximately the product of the performance functions for each smoke munition, assuming that the individual smoke clouds do not interact with each other.

The effect of munition placement may be seen (Figure (2)) when the smoke is deployed to the right of the line of sight or just outside the FLIR FOV. Here the performance does not drop off as rapidly because the combustion does not immediately effect the FLIR, but the smoke does. As before, the performance of the FLIR is degraded by the smoke that eventually disperses. It should be noted that the length of time that the smoke completely degrades the FLIR's performance depends on several variables and in cases where the smoke munition is deployed outside the FLIR FOV and only some of the smoke cloud diffuses into the FOV, the performance may not be completely degraded.

Conceivably, non conventional, spectrally selective smokes/obscurants could be developed. As an example, smoke that is more effective in the visible and the far IR than in the mid IR might have a performance function such as is shown in Figure (3). This performance function shows the greater degradation of the visible and FLIR type sensors over the mid IR sensors. It may be noted that this curve demonstrates a sharp cut-off of performance followed by a period of consistent degradation and a diffuse tail off to no degradation. This behavior is based on the hypothesis that a spectrally selective smoke/obscurant such as this would not be hygroscopic, but would almost instantly be dispersed and only gradually removed by diffusion and settling.

A problem of common interest is that of smoke that is spread homogeneously over the battlefield and maintained. This commonality is largely due to the fact that this is the easiest smoke effect to model because the smoke tends to be well behaved with respect to the class variables. The performance function for this case when all thermal sources are out of the FOV is demonstrated in Figure (4) for the eye and the FLIR. This may be compared with Figure (3) to demonstrate the spectral selectivity of the non conventional smoke compared to a conventional smoke. The wavelength dependence of the performance is common to many smokes. The smoke is, of course, sufficiently thin for this set of variables used for Figure (4), that performance is not completely degraded.

Because of the simplicity of modeling this type of smoke, initial test simulations were performed using a MIRADCOM program, PERTAM (PERformance Tank-Antitank Model). (14,15) This model is an extremely simple simulation of conflict between one ATGM site and three tanks. Four cases were considered; unaided eye, ATGM site with FLIR, Tanks with FLIRs, and both ATGM site and Tanks with FLIRs. The smoke density was sufficiently thin to permit 1200 m visibility. This density was chosen so that generic FLIR performance in the smoke would be approximately equal to eye performance without smoke. Three parameters were calculated as functions of ATGM reload time; the probability of ATGM site being destroyed, the expected standoff range of the engagement, and the expected number of tanks destroyed per engagement. These parameters are shown in Figure (5). It may be seen that while equiping a tank with a FLIR improves its performance in a smoke environment regardless of whether the ATGM site has a FLIR or not, this improvement is apparently not as significant as that realized by equiping the ATGM site with a FLIR.

It must be noted that these results are intended to only be demonstrative because of the simplicity of the model. These results, however do serve to demonstrate that smoke effects on the battlefield may be parametrized for FOF modeling and still provide useful, timely results. Work is currently inder way to improve the accuracy of the model and to introduce parametric models of other smokes/obscurants and sensors.

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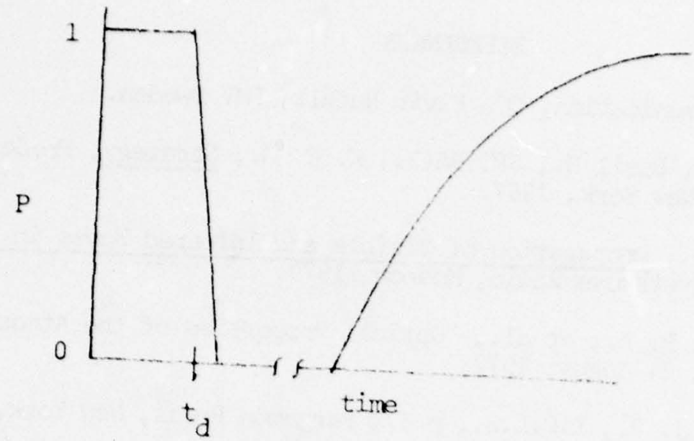
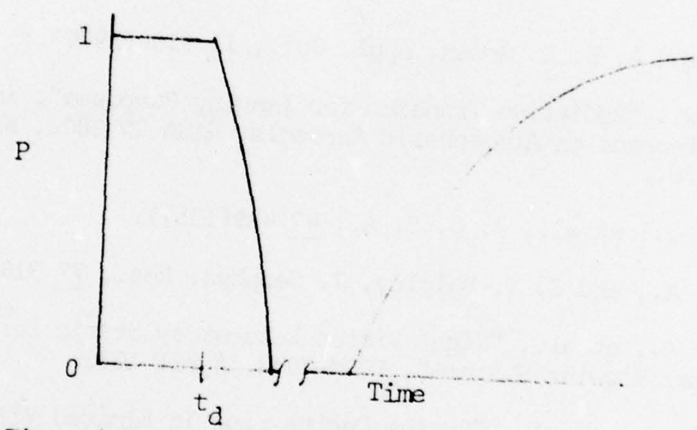
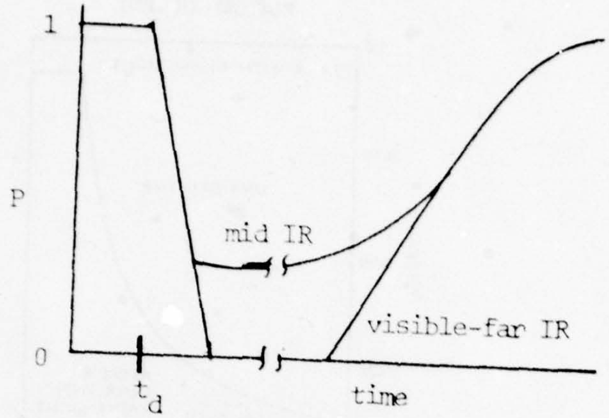


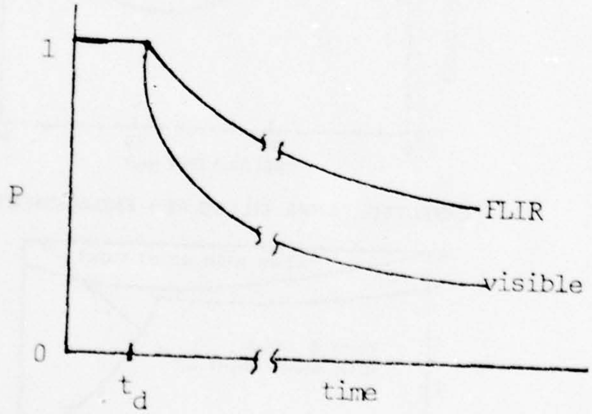
Figure(1). Performance function of generic FLIR when smoke is deployed along target-FLIR line of sight.



Figure(2). Performance function of generic FLIR when smoke is deployed outside FLIR FOV.



Figure(3). Performance function of non conventional smoke



Figure(4) Performance function for large area smoke deployed outside FOVs.

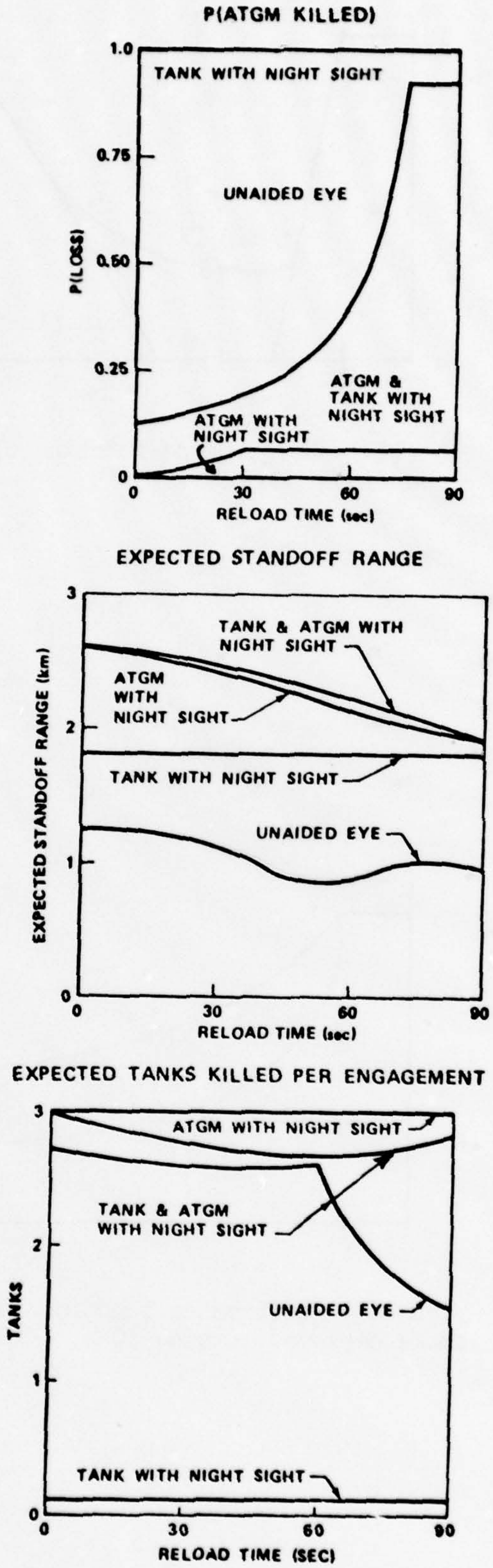

P(ATGM KILLED)
TANK WITH NIGHT SIGHT
UNAIDED EYE
ATGM & TANK WITH NIGHT SIGHT
ATGM WITH NIGHT SIGHT
P(LOSS)
RELOAD TIME (sec)
EXPECTED STANDOFF RANGE
TANK & ATGM WITH NIGHT SIGHT
ATGM WITH NIGHT SIGHT
TANK WITH NIGHT SIGHT
UNAIDED EYE
EXPECTED STANDOFF RANGE (km)
RELOAD TIME (sec)
EXPECTED TANKS KILLED PER ENGAGEMENT
ATGM WITH NIGHT SIGHT
TANK & ATGM WITH NIGHT SIGHT
UNAIDED EYE
TANK WITH NIGHT SIGHT
TANKS
RELOAD TIME (SEC)

FIGURE 5

TITLE: Battlefield Electrooptical System Effectiveness Model Study

AUTHORS: Dr. Ralph Zirkind, Mr. Richard E. Forrester and Mr. Adrian G. Linz

ABSTRACT: The results of an on-going program to develop an integrated model to measure the effectiveness of electrooptical systems in land combat are presented. In particular, we discuss the target acquisition algorithms for passive systems, their insertion into CARMONETTE and the necessary changes to CARMONETTE for their accommodation. Finally, the results of several simulations are presented.

BATTLEFIELD ELECTROOPTICAL SYSTEM EFFECTIVENESS MODEL STUDY

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and Mr. Adrian G. Linz*

(General Research Corporation and Night Vision Laboratory)

1. Introduction: This research program was initiated in 1974 and has as an overall objective the development of a tactical electrooptical effectiveness model where effectiveness was to be measured in the combat simulation model, CARMONETTE.** The first phase efforts are reported in Ref. 1.

The results of the Phase I study were encouraging enough to plan under Phase II for the actual programmed inclusion of a search model into CARMONETTE and to refine the search model itself.

At the initiation of Phase II, Dr. Zirkind developed a new search/detection model and a recognition model. These algorithms were examined and validated by NVL within their range of applicability. These inclusions were made under Phase II.

As an integral part of the CARMONETTE simulation they necessitated additional modifications to the simulation so that the parameters necessary to the search model would be available as needed. These parameters included such things as a definition of the sector of responsibility for each combat unit, the amount of unmasked land in his sector that was visible to him (available for search), calculations of intrinsic contrast and atmospheric attenuation of that contrast, and a drastic modification of the comparison of random number with probability of target acquisition to determine when the latter occurred.

During 1976, the programming changes to the CARMONETTE model were made and debugged. Combat simulations were then performed as further tests of the newly-combined model. Three cases of nighttime combat resulted employing Image Intensifier and Thermal devices in low-echelon combat.

The evolving search model simulation was gaining credibility and included many of the properties necessary to a good simulation of the search process in a combat setting. It included a timely description of the area of search for each combatant with that area changing as a function of knowledge gained. It handled cumulative probabilities of

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**For a complete description of the CARMONETTE model, one is referred to "CARMONETTE" in three volumes, November 1974, prepared by GRC-OAD under Contract DAAG39-74-C-0128 for US Army Combat Analysis Agency.

detection and recognition as a function of time over stretches of intervisibility between opposing combatants (incorporating changing parameters automatically). It addressed the clutter problem in a simplified form. And at the center of each calculation was the search model fully incorporated for thermal and image intensifier devices. The results are reported fully in Ref. 2.

This paper is divided into two parts: (1) the details of the target acquisition algorithms; and (2) the changes to CARMONETTE and the results of several simulations. Finally, some observations about smoke are presented.

2. Target Acquisition Algorithms: A set of algorithms was developed by one of the authors (R. Zirkind) for the detection and recognition of targets in area search when optical/electrooptical devices are employed.* These are now discussed.

The cumulative probability of detection $P_d(t)$ for random search of a real scene by an observer employing an electrooptical device, e.g., image intensifier, TV or FLIR, where the scene information is displayed is given by

$$P_d(t) = P_\infty(r)\left[1 - e^{-(\eta t/\tau N k)}\right] \qquad (1)$$

where
- $P_\infty(r)$ = the probability at range, r, for unlimited viewing time
- τ = mean time to detection in uncluttered scene
- η = scan efficiency if scene area > projected area
- N = area of scene/projected area of field of view ≥ 1
- k = clutter term
- n = 0.55 for 0.1 ft-L $\leq B \leq$ 10 ft-L

A study of available literature has yielded an expression for the mean time, τ, namely

$$\tau_D = 0.52 + \frac{.016}{\phi(x)}\left[\frac{\Theta_D^2}{\Theta_T^3 \cdot C^2 B^n}\right], \text{ in seconds} \qquad (2)$$

where
- $\phi(x)$ = normal probability integral
- X = $(C_r-1)/.48$
- C_r = target contrast/threshold contrast
- Θ_D = angular subtense of display, degrees
- Θ_T = angular subtense of target, degrees
- C = percent contrast (target-background/background)
- B = scene or display luminance in ft-Lamberts

The threshold contrast is defined here to be 2.65 times the value proposed by Blackwell.

*A complete derivation of the algorithms and validation will be published in a forthcoming issue of the Journal of Defense Research.

The scan efficiency has been estimated to be given by the expression

$$\eta = \frac{1}{2} + \frac{1}{1+N}$$

or, $N \to \infty$, $\lim \eta \to 0.5$. The latter is in agreement with observations at Fort Ord (CDEC).

Finally, in the event clutter is present, that is, target-like objects in the field-of-view, the mean time τ in Eq (2) will increase by the factor k. This factor is defined in Eq (3)

$$k = \nu \exp\left[\frac{.7}{[(1+\Delta\Theta)\cdot(1+\Delta C)}2\right] \qquad (3)$$

where ν = number of clutter points, $\nu \geq 1$

$\Delta\Theta$ = the ratio, angular subtense difference between the true target and non-target ÷ angular subtense of true target

ΔC = the ratio, contrast difference between target and non-target ÷ contrast of the true target

In a similar fashion an algorithm for the mean time for recognition has been developed. It is given by

$$\tau_R = 0.52 + \frac{\nu}{\left[\frac{(C-2.34)^{.639}}{\exp\left(\frac{1.65}{\Theta}-1\right)} - 3.02\right]}, \text{ in seconds} \qquad (4)$$

where ν = no. of target-like objects (targets and clutter) in field of view

C = percent contrast

Θ = target size in milliradians

The cumulative probability of recognition is then

$$P_R(t) = P_\infty(\text{recognition}) \left|1-e^{-\frac{t}{\tau_R}}\right|$$

The above can be applied to eye if we assume the eye subtends about 20°.

Let us now consider the evaluation of several parameters in Eq 2, namely n, contrast, C, and target size, Θ_T.

The exponent n is a function of scene or display luminance and in the event the latter exceeds 10 ft-L then n = .75 for values of 10 ft-L < B $\leq$ 100 ft-L.

For a real scene we are interested in the contrast received by the observer, C_r. Let us define the intrinsic contrast C_O, the contrast at the target for a device with a photocathode (TV, image intensifier, etc.) as

$$C_o = \frac{|M_2 - M_1|}{M_1}$$

where C_o = intrinsic contrast
M_1 = image intensifier background reflectance (function of concealment)
M_2 = image intensifier target reflectance

The received contrast, C_r is then in percent

$$C_r = \frac{C_o}{1 + \frac{K_3 P_2}{C_G T M_1}} (\times 100) \tag{6}$$

where $K_3 = 1 - e^{-\sigma_s R}$ (scattered component)
$C_G = \frac{1}{2}(1 + Rg)$ (sky-ground ratio)
$T = e^{-(\sigma_s + \sigma_a)R}$ (atmospheric transmittance)
$P_2 = \frac{1}{e_c}\int_{0.4}^{0.9} B(\lambda)Q(\lambda)\; d\lambda$ (flux density)
R_g = the reflectance of the ground
σ_s = atmospheric scattering coefficient
σ_a = atmospheric absorption coefficient
R = range to target in meters
$B(\lambda)$ = spectral radiance of the night sky in $\frac{\text{watts}}{\text{cm}^2\text{-steradian-micron}}$
$Q(\lambda)$ = spectral sensitivity of the photocathode in amperes/watt
e_c = electron charge in coulombs

Clearly the factors in Eq 6 depend upon the environment, the scene and the device characteristics. In the latter case, we have assumed no contrast loss through the device. Finally, the display luminance (ft-L) for the image intensifier is given by

$$B = .093\ GA \tag{7}$$

where G = the light-flux gain of the Image Intensifier, in ft-L/ft-candles (an input value: $G \sim 3.5 \times 10^5$)

and $A = \frac{10^4 \pi \gamma}{4(f_n)^2} \int_{0.4}^{0.9} B_\lambda K_\lambda R_{b\lambda} d\lambda$ [A is in lumens/m^2.]

$$= 7854 \frac{\gamma}{(f_n)^2} \int_{0.4}^{0.9} B_\lambda K_\lambda R_{b\lambda} d\lambda$$

where γ = device transmission (typical value = 0.92)
f_n = image intensifier system f-number (typical value is 1.6)

K_λ = photopic luminosity curve in lumens/watt
B_λ = night sky brightness in watts/$(cm^2)(\mu)(\Omega)$
$R_{b\lambda}$ = background reflectance and is a function of λ and of the concealment index of the square occupied by the target

The procedure for a thermal viewer is different and is now presented.

The display contrast, C_r, in percent is calculated as follows:

$$C_r = (SNRV) \cdot (NE\Delta T) \cdot C_S \cdot 100 \tag{8}$$

$$(SNRV) \cdot (NE\Delta T) = \tau_e \cdot A \cdot (TF)_h (TF)_v \left| e_T \Delta T + (e_T - e_B) T_B / 4 \right|$$

where (SNRV) = signal-to-noise ratio, video
(NEΔT) = noise equivalent temperature difference
τ_e = effective atmosphere/optics transmittance
$(TF)_{h,v}$ = amplitude response function; horizontal, vertical
A = fraction of target cross-sectional area if less than resolution element area
e_T = mean target emittance
e_B = mean background emittance
ΔT = temperature difference between target and background in degrees Celcius
T_B = background temperature of battlefield in degrees Kelvin
C_S = contrast at display saturation
$\tau_e = \tau_o e^{-(.00036RH_o)}$ (attenuation is a practical fit to available data)
H_o = amount of precipitable water (units of cm) in a horizontal column of atmosphere of 1 km in length (calculated in preprocessor from input temp. and humidity)
τ_o = a system parameter of the device
R = range to target in meters

The display luminance is considered to be 10 ft-L; however can be adjusted to fit actual values. Current values for CRTs $\leq$ 50 ft-L

Now let us consider the calculation of the displayed target size, Θ_T, and consider first the thermal viewer.

The angle, Θ_T, subtended by the displayed target is calculated as follows:

$$\Theta_T = \frac{WTD + HTD}{2d_D} \left(\frac{180°}{\pi} \right) \tag{9a}$$

where $$WTD = \frac{W_T}{R} \cdot \frac{D_H}{(FOV)_{AZ}} \cdot \frac{180}{\pi}$$

$$HTD = \frac{H_T}{R} \cdot \frac{D_V}{(FOV)_{EL}} \cdot \frac{180}{\pi}$$

$(FOV)_{AZ}$ = device field-of-view, azimuth (degrees)

W_T = observed target width in meters
H_T = observed target height in meters
R = range to target in meters
$D_{H,V}$ = display dimensions, horizontal and vertical in meters
d_D = viewing distance in meters such that CRT display subtends about 18°

One will recognize that Eq (9a) may be written as

$$\Theta_T = \frac{W_T}{R} \quad \frac{M_H + M_V}{2} \quad \frac{180^\circ}{\pi} \tag{9b}$$

where M_H, M_V are the magnifications in the horizontal and vertical directions respectively. That is, we have substituted the following expressions

$$(\Theta_D)_H = M_H \cdot (FOV)_H \tag{10}$$

$$(\Theta_D)_V = M_V \quad (FOV)_V$$

$$(\text{NOTE:} \quad \Theta_D = [(\Theta_D)_H + (\Theta_D)_V]/2.)$$

If the viewing device utilizes an eyepiece as the last stage in the optical system then $M_H = M_V = M$ and we can write for the target size and display angular subtense

$$\Theta_T = \frac{W}{T} M \cdot \frac{180^\circ}{\pi} \tag{11}$$

$$\Theta_D = M \cdot [(FOV)_H + (FOV)_V]/2$$

Finally if the field is circular then Eq (11) becomes

$$\Theta_D = M \cdot FOV \tag{12}$$

The last two equations, for example, will apply to an image intensifier.

3. Modifications to CARMONETTE: The incorporation of the above algorithms into CARMONETTE impinged primarily on those CARMONETTE submodels associated with surveillance and unit movement. The four levels of CARMONETTE target location information were retained but redefined operationally. The scan cycle and clock structure were retained but the Markov process of probability-per-cycle-vs-random-number gave way to the comparison of one random number with a cumulative probability over time from the inception of intervisibility to its interruption. A sector of search-responsibility for each combat unit was incorporated as a framework for the Zirkind, Target Acquisition Model along with a delineation of masked and unmasked terrain within that sector. Performance characteristics of thermal devices and image intensifiers were incorporated to employ the new algorithms. The detection process for one scan cycle is given in Fig. 1.

The cursory description of the above equations as they now function within CARMONETTE is as follows. Equation (2) is employed to get a mean time to detection for current parameters for one field of view of the device. The resulting mean time is in turn modified by the area to be searched and by clutter as defined by Eq (3). This expanded mean time is

then used in Eq (1) to get a probability of detection for one scan cycle as defined in CARMONETTE. The result of Eq (1) is then added to a cumulative probability of detection for the observer concerning the potential target. This process is repeated each scan cycle until the cumulative probability exceeds a random number (between zero and one) that had been drawn at the inception of the above process and the detection of this target occurs. The process is used only when the potential target is intervisible with the observer and is in the search area of the latter.

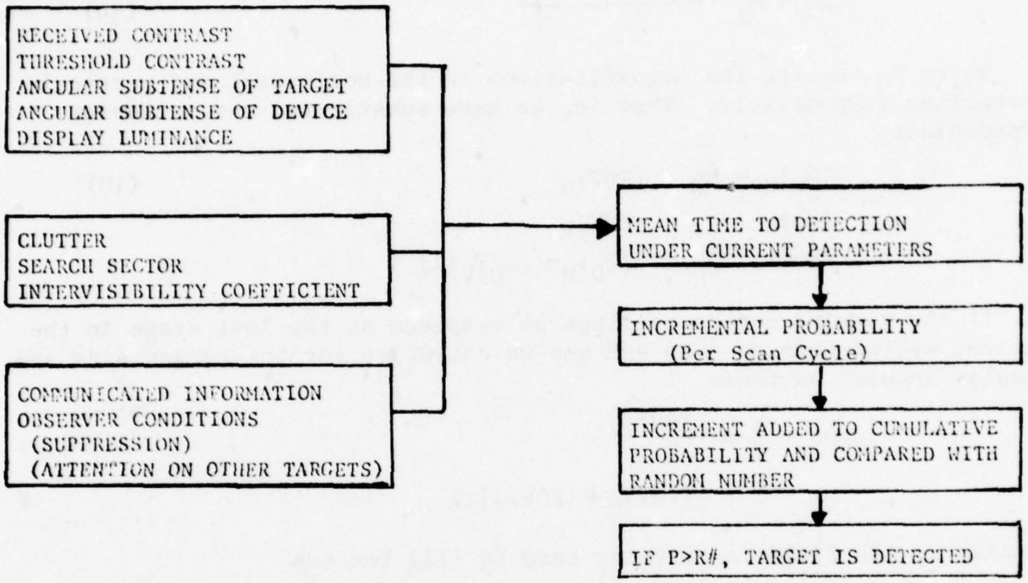


Fig. 1 - Detection Process for One Scan Cycle

In the event that the observer is communicated information about the potential target before he detects it, his probability of detection is augmented.

Upon the occurrence of detection by the above process, a similar procedure is employed to tell when recognition occurs.

The observer can decide to fire at the target with detection information only but suffers a corresponding degradation in weapon performance. Or if he waits for recognition, he then realizes full weapon capability under the existing conditions.

If the potential target disappears from view (i.e., is no longer intervisible with the observer) before detection occurs, the procedure is halted and the accumulating probability erased. If the potential target is either far enough away or is showing sufficiently low contrast with his surroundings so that the viewing device limitations come into play, then he might remain undetected during the entire battle; this depends on the asymptotic probability of detection approached over time and on the particular value of the random number against which it is being compared.

3.1 Levels of Target Location Information: Previous versions of CARMONETTE modeled four states of knowledge about targets with accuracy of information increasing monotonically from State 1 through the intermediate states to State 4. The four states have had operational definitions as follows:

1 - No information: no firing
2 - "Nearest Square": artillery can be called on target
3 - "Erroneous pinpoint": artillery and direct fire (with no hits from direct fire)
4 - "Pinpoint": artillery and direct fire (assessed for probability of hit by direct fire)

The current version of CARMONETTE employs all four of the above states but changes their operational definitions in the following way. State 3 represents detection with resulting possibility of firing but with a degraded hit assessment. State 4 represents recognition (with full weapon performance if the seeker decides to fire). State 1 continues to represent no information. State 2 represents communicated information; artillery can be called on State 2 targets.

An advantage of operationally redefining information levels 3 and 4 to correspond respectively to detection and recognition is that it aligns these levels with a wealth of psychovisual experimentation and allows for direct input of experimental values.

The retention of level 2 as communicated information gave the following flexibility to model development. It was immediately usable information to the recipient of the communication (and was so programmed) in that he could temporarily narrow his search area in order to decrease the normal time to detection. Also level 2 information could, in the future, be employed to represent received information cues from such things as weapon signatures, dust clouds, movement, etc.

As the four levels are now defined, they do not lead to the firings on false targets that is so characteristic of previous CARMONETTE versions. (See the previous definition of level 3 above.) Such extra firing is characteristic of real battles and must now be included in a different manner. This will be treated in a revised version of the target acquisition model, namely as a false alarm rate associated with the detection and recognition process.

3.2 New Rule Structure: A new procedure for processing target acquisition is used and is a compromise between time-slice and critical event methods. During continuous intervisibility between opposing combat units (tanks, APCs, etc.), cumulative probabilities of detection as a function of time are maintained for all combinations of intervisible opponents.* A given pair of opponents may be intervisible several times during a battle. For such a pair, the cumulative probability of detection of each about the other begins to grow at the time they become intervisible. The probability

*Each opponent must also be in the search area of the other to be considered here.

continues to grow during the time that they remain intervisible until either detection occurs, intervisibility ceases, or the probability of detection remains less than a random number selected to compare against it. The rate of growth of the probability is dependent upon the range of separation, viewing device employed, time available for search, etc. As these parameters change (c.f., the opponent's range of separation decreases), the rate of growth of the probability changes correspondingly. In order that the rate of growth of the probability remain respondent to changes in the parameters, a periodic check of the parameters is made. The period of time between checks of the parameters is called the surveillance interval and is dependent on the viewing device employed.

As stated, the probability ceases to grow if intervisibility ceases or detection occurs. When intervisibility ceases, the cumulative probability is erased (for each of the two opponents) and the process will commence anew when they next become intervisible. If detection occurs for one of the two opponents, about the other, the cumulative probability for the successful one is erased and the latter is given detection information (state 3) about his opponent. This detection has occurred by virtue of the cumulative probability exceeding a random number which was selected at the initiation of intervisibility.

Once detection occurs, then the same process is employed for recognition (state 4 information) as long as intervisibility continues with probabilities appropriate to recognition replacing those appropriate to detection.

The above procedure thus simulates times to detection and recognition from the inception of intervisibility and does so as a function of changing parameters. It also succeeds in isolating those opponents that are never found by certain intervisible enemy simply because the cumulative probability reaches an asymptotic value before exceeding the corresponding random number.

The incremental probabilities of detection and recognition are constructed from the asymptotic probabilities associated with the existing parameter values along with the mean time to detect or recognize (also associated with existing parameter values) as given by the Zirkind equations.

The new rule structure on cumulative probabilities of detection at present applies to image intensifiers and thermal devices. Other seeker types remain connected to the Markov chain methodology. This efficiency can be readily remedied.

In order to implement the search/detection algorithm, it was necessary to identify the area of search for each combat unit. This is done by giving left and right search sector bounds to each combat unit and by sampling the terrain within the search sector to identify

the actual portion of that terrain that is intervisible with the combat unit and hence available for search. These unmasked portions of land go under the name of intervisibility coefficients. The intervisibility coefficients identify the fraction of land that is unmasked in the range interval containing the target. The calculation of these coefficients consist of running a set of terrain profiles from the observer position at equal angular increments (10°) across his search sector, collecting the masked and unmasked portions of these profiles as a function of range interval, and thus generating the coefficients. Fig. 2 depicts one of these profiles. Beginning at (X_s,Y_s), the location of the observer, and heading outward along the profile, the height of each subsequent square along the profile line is employed with the observer's height and with the distance from the observer to calculate a mask angle, VM_n, in the vertical plane. This mask angle is then compared to the greatest mask angle found so far along the profile. If the mask angle just found exceeds the prevailing greatest mask angle, then the current square is intervisible with the observer and the most recent mask angle is retained as the greatest. Otherwise, the current square is said to be masked from the observer's view and the intervisibility of the next square along the profile is checked, etc. In this way, the fraction of intervisible squares within each range interval along the profile is determined. The same procedure is employed for the other profiles in the observer's search area. Then for each range interval, the average fraction of unmasked terrain over the set of profiles is calculated and retained as the intervisibility coefficient for that range interval for the observer as long as he remains in that location.

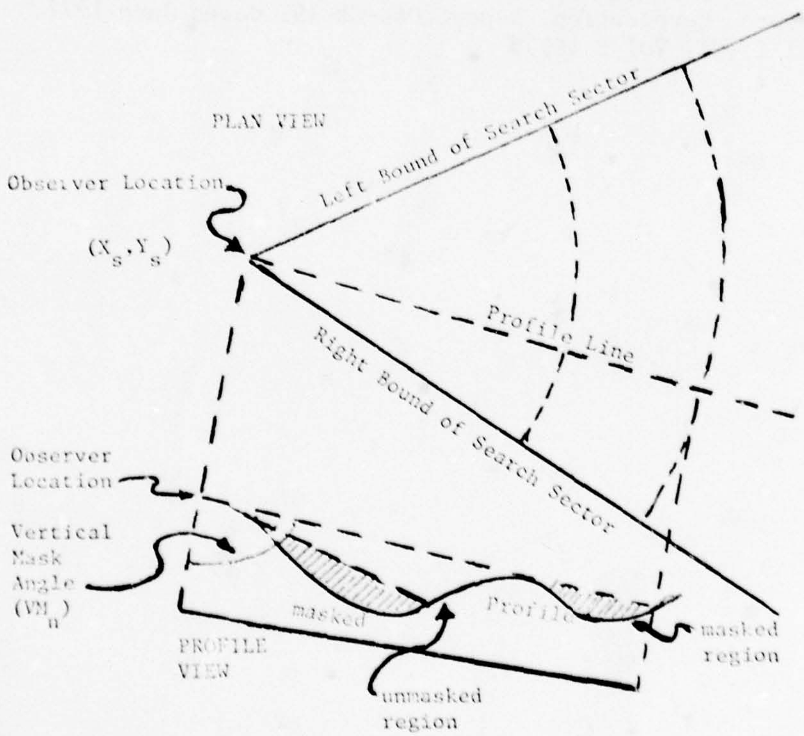


Fig. 2 - Profiling to Determine Unmasked Fraction of Search Area

The intervisibility coefficient is used along with the area of search to modify the mean time to detection that is defined by Eq (2) The intervisibility coefficients were essentially to be samplings of the line-of-sight function in CARMONETTE.

The detailed results of three different games are presented in GRC Report CR-191, Part II.

Addendum: The target acquisition model presented earlier can readily utilize a smoke model; that is, the mean detection time contains the contrast explicitly. Since smoke reduces the received contrast its effect is to increase the mean detection time, i.e., $\tau_D \sim C^{-2}$. Hence a reduction of contrast from 50% to 5% will increase the detection time by a factor of 100 with the serious reduction in probability of detection. This approach has been used by one of the authors (Zirkind) in the formulation of a smoke model.

References

1. Zirkind, R. and Forrester, R. E., "Tactical Electrooptical Effectiveness Model, Final Report— Phase I" (U), General Research Corporation, Report OAD-CR-121 dated Aug 1975, (CONFIDENTIAL).

2. Zirkind, R. and Forrester, R. E., "Tactical Electrooptical Effectiveness Model, Final Report— Phase II" (U), General Research Corporation, Report OAD-CR-191 dated June 1977 (Vol 1 (U), Vol 2 (C)).

ABSTRACT

TITLE: DUEL3, A Quick and Easy Simulation of Armor or Infantry Duels

AUTHOR: Fred Bunn

ORGANIZATION: US Army Ballistic Research Laboratory (301-278-5534 or Autovon 283-5534)

ABSTRACT: The DUEL3 model should be generally useful for studying any duel where the range and exposure of the combatants stays relatively constant during the course of a single duel. DUEL3 computes the effectiveness of the duelers as a function of these parameters:

- accuracy (in x and y)
- precision (in x and y)
- range
- open fire times
- exposure/concealment
- firing cycle
  - number of rounds in a burst
  - time between bursts
  - time between rounds in a burst

The model accounts for the fact that when many rounds are flying simultaneously, both combatants can die: thus neither wins. The method of accounting for this will be discussed in detail.

Preliminary experimentation with the model simulating tank duels verifies the overwhelming importance of getting the first shot off quickly.

The model was designed to "talk" to the user and guide him as he changes parameters and controls its operation. The model was intended to be so easy to use that a person could sit down at a terminal and operate it with little or no prior instruction. In addition, the program was written to be very fast, quite modular, portable, and easy to maintain or modify. For these reasons, Structured Programming was used throughout. These qualities of a well designed program will also be discussed.

ESTIMATED TIME REQUIRED FOR PRESENTATION: 20 minutes plus 5 minutes for questions and answers

CATEGORY: Special Session: Combat Analysis

TITLE: DUEL 3, A Quick and Easy Simulation of Armor or Infantry Duels

AUTHOR: Fred Bunn, US Army Ballistic Research Laboratory

About a year and a half ago I got involved in the study of armored systems. My first job was to study AAAC, a medium caliber, high rate of fire anti-tank gun: sort of a slow machine gun for killing tanks. I didn't know much about the dynamics of armored combat, so I began looking around for models of simple combat: duels. I found two and got them running. At the same time I wrote a series of three small but increasingly more realistic models of the duel. DUEL3 is the third and probably not the last in that series.

The objectives of DUEL3 are:

To provide a tool for understanding the dynamics of simple combat, and

To evaluate some key parameters of the AAAC system.

The major current assumptions are:

The duelists will be motionless,

The duelists may be represented as a circular target,

The duelists do not adjust fire on sensing misses, and cumulative damage may be ignored.

The first assumption, lack of motion, can later be handled by adding biases for firer or target motion perhaps. The second, that the target can be treated as circular, we plan to test at a later time by substituting a more realistic matrix model, and seeing if it makes much difference. The third assumption, that we do not adjust fire on sensing misses, we can probably do something there too. The fourth assumption, about cumulative damage: we're going to have to live with that for a while - we don't have a handle on how to put it in the model right now.

DUEL3 computes the effectiveness of two duelists as a function of these parameters: number of rounds in a burst, time between rounds, time between bursts, accuracy and precision, range, presented area, and open fire time. I wrote the model to simulate duels in general but tank duels in particular.

The model is an event-sequenced, expected value model currently running on an 1108 computer. It is written in a standard, structured FORTRAN and should be easy to move to any FORTRAN computer. I say that after putting the same large program on 3 different machines.

DUEL3 begins by reading in a table. The table contains:

A default value for each parameter,

The min and max value, and

The name plus a short definition of the parameter. The program reads values for blue, for red, and for game control. Figure 1 shows a diagram of the default file with a sample card image that is stored in the file.

After reading in the default table, DUEL3 prints out a message saying 'TYPE H FOR HELP', then it waits for our input. Let's suppose we don't know what the legal inputs are, and we type H.

DEFAULT FILE

	DEFAULT	MIN	MAX	NAME - DEFINITION (UNITS)
BLUE	1.0	0.1	15.0	DT1 - TIME BETWEEN RDS (SEC)
RED				
GAME				

Figure 2 is a condensed form of what we'd see. First let me make two comments: on the left is the command word. Each command begins with a unique letter. You can type in just the first letter or the whole word if you wish. Second, the computer will print out one line for each case unless you ask for more detailed output. A case is normally one duel at each of 11 ranges.

If you want a line printed for each of the 11 duels just type in 'D' or 'DUEL PRINT' and a carriage return. The program will set the appropriate print flag.

If you want a line printed for each round fired in each duel, type 'E' or 'EVERY PRINT' followed by a carriage return.

Typing 'H' or 'HELP' at any time tells the program to write a fresh copy of this 'command menu'.

If you want to see the current values of each variable, simply type 'L' or 'LIST'.

When you're done changing variables and want to see their effect, type 'R' or 'RUN'.

At the end of your session with DUEL3 type 'S' or 'STOP'.

The 'T' or 'TRACE' command traces the logic of the program and would be especially useful for someone modifying the program.

The last command is used to change weapon system parameters. The 'LIST' command gives you a 'parameter menu'. At any time you can change any parameter simply by typing in it's index number, a comma or blank and the new value (followed of course by a carriage return). For example, if we wished to change the tenth parameter to 5.3, we could just type 10, 5.3 and the program would take care of it.

When you attempt to give a parameter a new value, the program checks it carefully and either echos back the new value along with the definition of the parameter, or else it tells you exactly why it rejected the value. This, of course, saves a lot of time over the old batch, non-checking method where a person wastes a lot of time because he left out a card or got a number in the wrong field, or just used an unrealistic value. Then the program would run for a fair amount of time and die in some mysterious place with a divide check error.

At this point let me say a little about my design philosophy. I believe programs should be built of modules no longer than a page. Happily, the authorities are in general agreement with me. DUEL3 modules are rarely longer. I believe programs should be well commented: DUEL3 is about 20% comments. Programs should be understandable--which brings up the subject of structured programming.

About 5-7 years alo a new set of buzz words began popping up in the literature: structured programming, top-down programming, and a few others. They all refer to a set of concepts for more accurately producing programs in less time. They are becoming accepted in the programming community. Unfortunately, as I talk to analysts who use FORTRAN, I find 70% of them are totally unaware of these new ideas.

I personally am sold on structured programming, I suppose it allows me to code faster: its hard to estimate. I am sure it makes my programs more readable, more understandable, and consequently, more maintainable. If you have never heard about these new concepts, I urge you to check them out. Ed Yourdan's book "Top-Down Structured Programming" is a

C O M M A N D S

COMMAND	RESULTING ACTION
DUEL PRINT	PRINT RESULTS OF THE DUEL ONLY.
EVERY PRINT	PRINT RESULTS OF EVERY RD FIRED.
HELP	PRINT THIS MESSAGE AGAIN.
LIST	PRINT A LIST OF THE CURRENT VALUES.
RUN	IMMEDIATELY RUN WITH CURRENT VALUES.
STOP	STOP THE PROGRAM.
TRACE	TRACE PROGRAM LOGIC.
I, X	STORE X IN THE I(TH) PARAMETER.

FIGURE 2

good place to start. I also recommend Clement L. McGowan's book, "Top-Down Structured Programming Techniques".

Lastly, if at all possible, a program should be short and cheap to run. I suspect most large programs spend most of their time computing things below the noise level. DUEL3 is about 20 pages long and costs a dime a case.

Now let's talk about how we calculate effectiveness at any instant. Figure 3 illustrates this. The duel is always in one of four states: both duelists are alive (represented by the clear area): blue wins because he is alive and red is dead (represented by the positively sloped hatching): red wins when red is alive and blue is dead (indicated by negatively sloped hatching): or neither wins because both are dead (represented by cross hatching).

If only one duelist has rounds in the air at any given time, life if fairly simple, and we have the situations shown in the top row of boxes. Box one shows time zero: no rounds have arrived and both duelists are alive. In box two, we see that a red round has arrived. The clear area is now smaller and is in fact proportional to the probability that both are alive. The probability red wins is now non-zero. In box four, a second blue round arrives and the probability of a blue win becomes the sum of these two areas. Mathematically, updating the state probabilities is very simple, we just decrement the clear areas by the single shot kill probability and increment the appropriate win state by the same amount.

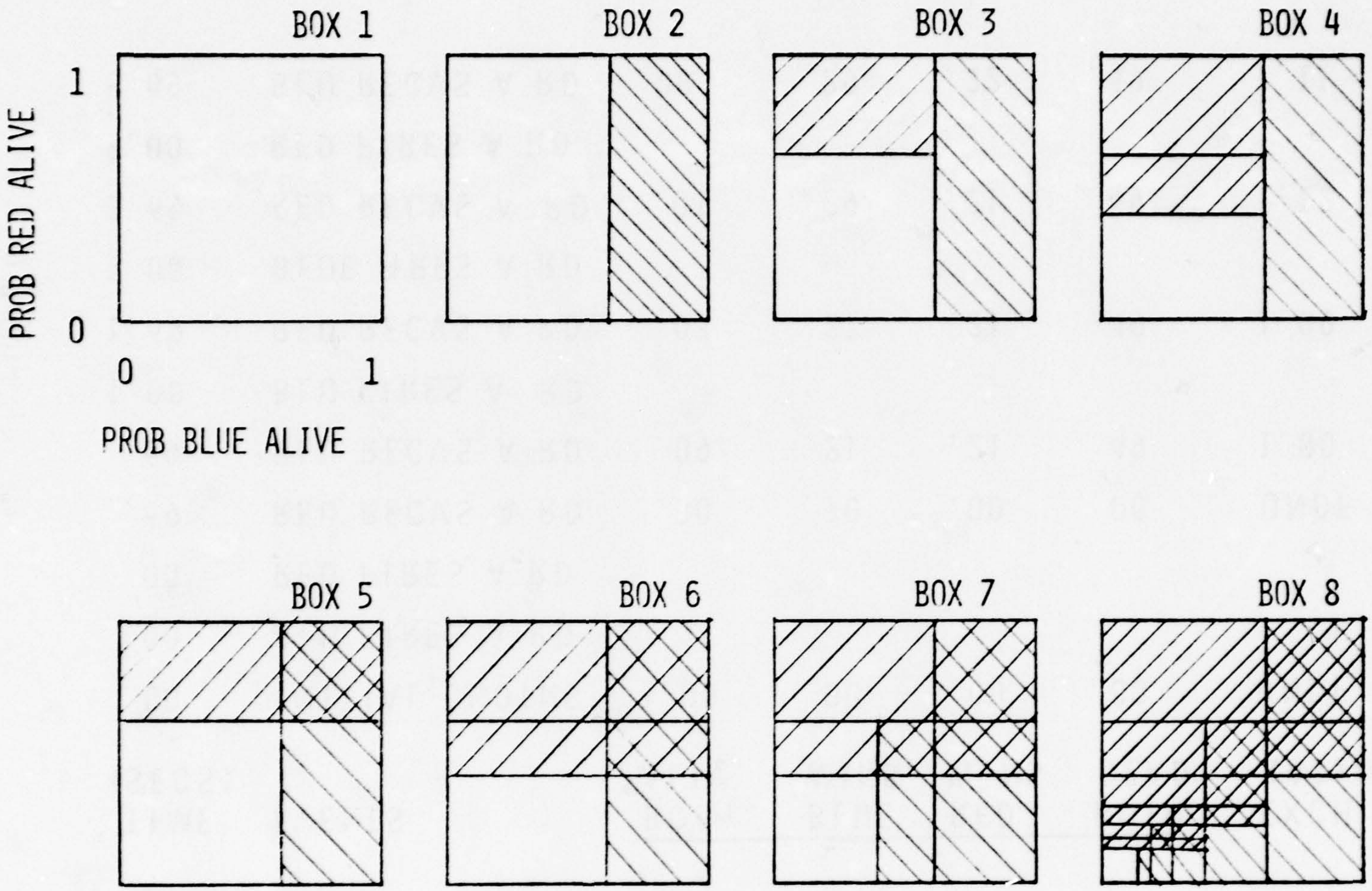
In actual fact, life is not so simple. The faster rounds are fired and the longer they are in flight, the more likely several rounds will be flying simultaneously. This introduces the possibility both duelists will die and neither will win. Let's go back to box two, where a red round has just arrived. If a blue round is in flight when this red round arrives, then there is a possibility of mutual extinction. This is represented in box five. Here we see a cross hatched area: the probability that neither wins. And now we notice that the red win state is smaller than previously. We had tentatively assigned red too large a probability and must now go back and make a correction.

Looking at box six, we see that there were two rounds in flight before the red round arrived. The probability of neither winning is growing. In box seven we see that a red round was launched between the arrivals of the two blue rounds and we have three cross hatched areas whose total area is proportional to the probability that neither wins and both are dead. Finally, in the last box we see that a number of additional rounds have been fired.

As it turns out, there is a set of reasonably simple, iterative equations for updating the state probabilities. They are shown in Figure 4.

This is the set of equations when a blue round arrives. On the left with double primes are the probabilities we wish to find: the probability of being in each state after the round arrives. On the right in single primes is the probability of each state just before the round arrived. And in the last 2 equations are the unprimed probabilities as they were when the round was fired. Finally the K is the single shot kill probability. Now let me run that by one more time. Double primes are after the round arrives, single primes are just before the round arrives, and unprimed is when the round was launched.

STATE CHANGES



EVENT HISTORY | STATE PROBABILITIES

TIME (SECS)	EVENTS	BOTH ALIV	BLUE WINS	RED WINS	BOTH DEAD	EXCH RATIO
.00	INITIAL CNDTNS	1.00	.00	.00	00	UNDF
.00	BLU FIRES A RD					
.00	RED FIRES A RD					
.69	RED RECVS A RD	.30	.70	.00	.00	UNDF
.69	BLU RECVS A RD	.09	.21	.21	.49	1.00
1.00	BLU FIRES A RD					
1.69	RED RECVS A RD	.03	.27	.21	.49	1.09
2.00	BLUE FIRES A RD					
2.69	RED RECVS A RD	.01	.29	.21	.49	1.12
3.00	RED FIRES A RD					
8.69	BLU RECVS A RD	.00	.29	.22	.49	1.11
16.69	BLU RECVS A RD	.00	.30	.22	.49	1.11

FIGURE 4

Looking at the X and B states, we see that whenever a blue round arrives, the increase in the B state is exactly equal to the drop in the X state. And looking at the R and N states, we see that the N state gains exactly what the R state loses. We see further that if the probability of red winning changed while the blue round was in flight, this factor will be non-zero.

A similar but not identical set of equations must, of course, be used whenever a red round arrives.

Now let's look at the history of a single duel as printed out by DUEL3 and shown in figure 5.

The weapon systems are identical except that red is firing a round every 8 seconds while blue is firing a round a second for three seconds and then waiting 8 seconds.

The initial conditions are that both are alive and the exchange ratio is undefined. At time zero both red and blue fire a round. At 0.69 seconds red receives a round and the instantaneous probability that blue wins is 0.70 and the 'exchange ratio' is still undefined. At the same instant blue receives a round and the probability both are alive drops by 0.21 to 0.09. This 0.21 quantity shows up in the red win column. Meanwhile the 0.70 blue win probability we had tentatively assigned in the previous line drops 0.49 and a 0.49 probability appears in the both dead column. Note also that the 'exchange ratio' is no longer undefined.

The duel continues with blue firing somewhat faster than red and the state probabilities settle out at the values shown on the last line. Because of the high single shot kill probabilities and the simultaneous firings of the first rounds the probability both die is nearly 50-50. Because blue is firing more rapidly, blue has a significantly higher chance of winning.

Next let's look at duels at each of a number of ranges. The default case calls for simulating duels at each of 11 ranges from 0 to 2,000 meters at 200 meter increments. In the prob-of-duel column the program prints out the probability that a duel occurs in an interval centered at the indicated range. These frequencies are based on WW2 data. Now looking at the first state probability: the probability that both combatants are alive at the end of a duel. Notice that because of our high kill probabilities there's little chance both survive except at the longest range. In the next column is the probability of a blue win. As the range gets longer the single shot kill probabilities drop and the effect of blue's burst firing begins to show up. Surprisingly, we see that as range increases, the chance of a red win increases too, but it's all at the expense of the next column, the neither win column. It seems counter intuitive that, since times of flight are longer, and the probability of simultaneous rounds is greater, that the neither win state is smaller. What is happening is that the first round from both systems are flying simultaneously and at short range they have a large effect while at longer range they have a smaller effect & some of the later non-simultaneous rounds come into play. In the final column we see exchange ratios. As you can see blue's advantage grows as range increases but not by a tremendous amount.

RESULTS OF DUELS

RANGE (METERS)	PROB OF DUEL	STATE PROBABILITIES BOTH ALIVE	BLUE WINS	RED WINS	BOTH DEAD	EXCH RATIO
0	.03	.00	.20	.16	.64	1.05
200	.18	.00	.22	.17	.61	1.06
400	.21	.00	.24	.18	.58	1.07
600	.18	.00	.26	.20	.55	1.08
800	.13	.00	.28	.21	.52	1.10
1000	.09	.00	.30	.22	.49	1.11
1200	.06	.00	.32	.23	.45	1.14
1400	.04	.00	.36	.25	.40	1.18
1600	.03	.00	.42	.13	.45	1.49
1800	.02	.00	.48	.17	.34	1.61
2000	.03	.01	.54	.21	.24	1.73

MEAN EXCHANGE RATIO OVER ALL RANGES IS 1.117

FIGURE 5

And finally down at the bottom we see the program has computed the weighted average of the exchange ratios. The next 3 figures will change a couple of the systems parameters.

In figure 6 we are changing the time between blue rounds, assuming a three round burst. Notice first that the vertical scale is logarithmic. This is especially appropriate for exchange ratios, of course.

Here we see how the mean exchange ratio varies as blue's rate-of-fire changes. First let me explain that the time between bursts is 8 seconds. Now if we start out with 8 seconds between rounds in blue's so-called burst, the blue system is identical to the red system and the exchange ratio shrinks, but not sharply.

In figure 7 we see how the mean exchange ratio varies as blue gets a head start on his first round. If blue starts firing at time zero and we vary red's start time we get this curve. If red's delay is near zero the exchange ratios are near unity. If red delays for a second, blue has a good chance to kill red before he gets his first round off. With further delays, of course, blue can get several killing rounds in before red's first round is fired.

In figure 8, we see a combination of effects. On the horizontal axis we are varying blue's rate of fire. On the lowest curve we show a two second headstart for red. Above that, a one second headstart. In the curve near the axis, both systems open fire at the same time. Then as we go higher we see a one, two and three second advantage for blue.

What we have here is a synergistic effect causing a ridge. If a system can be designed to put us on this ridge, all well and good. Blue moves from lower curves to higher curves by either concealing himself better or by detecting red quicker. If the duel occurs on one of the lower curves, there is little to be gained by cutting the time between rounds. However, if the duel occurs on the higher curves, you may be able to get a large pay-off by firing quickly inside the burst.

In closing, I would like to mention two areas which need to be improved perhaps in a DUEL4. First, we need to model the errors introduced when firing bursts. Second, we need to replace the circular target model with a matrix model.

RATE OF FIRE

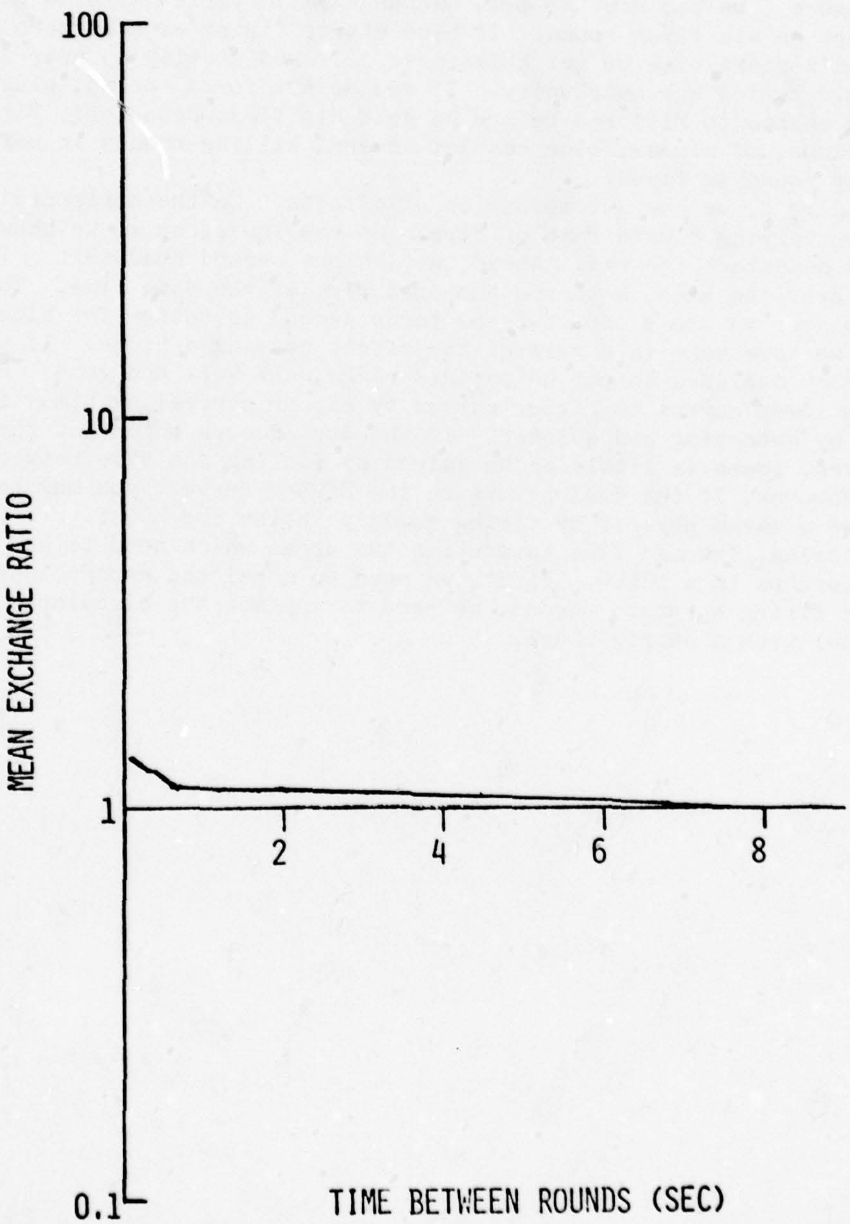


FIGURE 6

EFFECT OF BLUE 'HEADSTART'

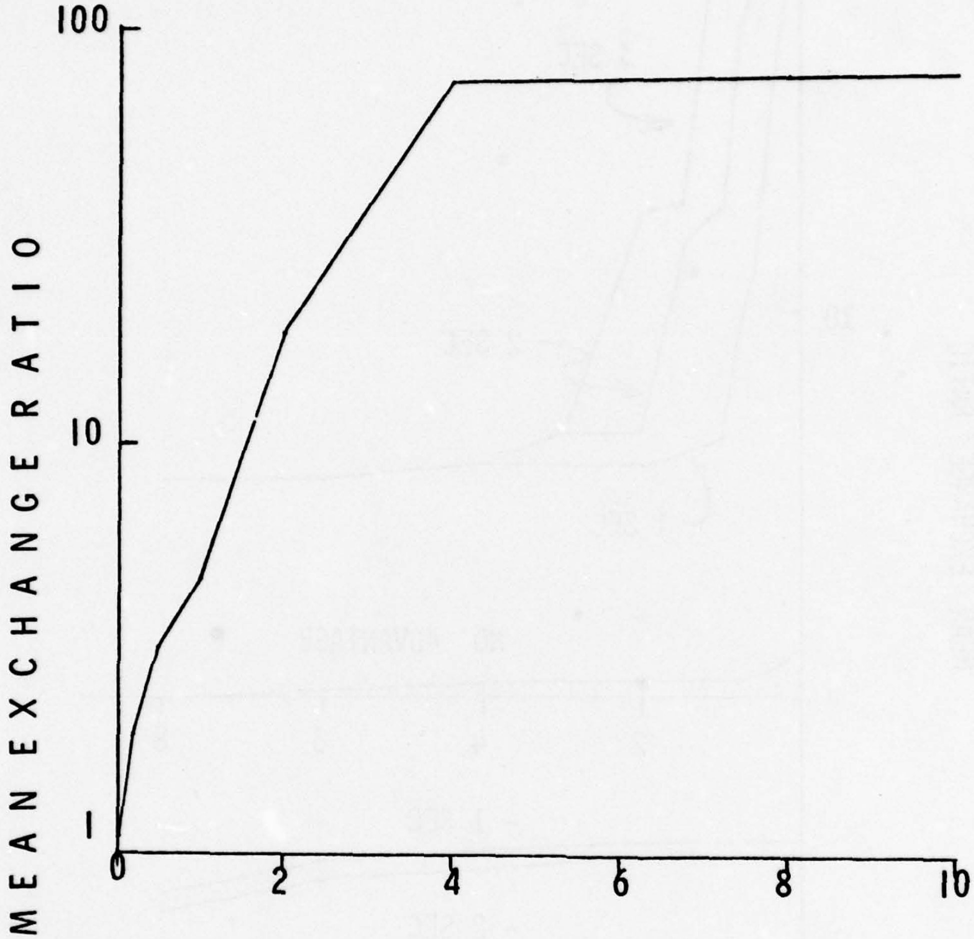


FIGURE 7

RATE OF FIRE

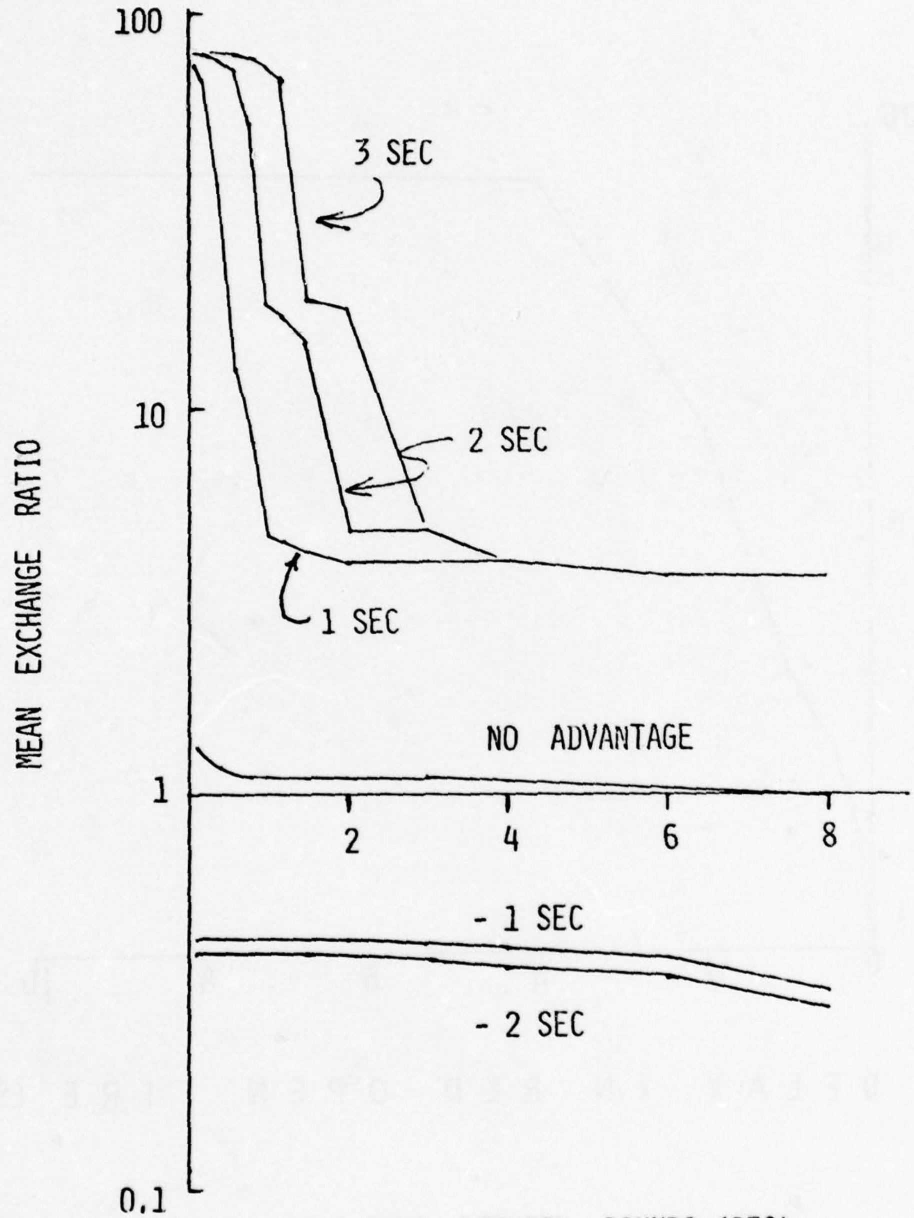


FIGURE 8

ABSTRACT FOR AORS XVI

TITLE: Investigations Into Air-to-Air Combat Between Helicopters

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ORGANIZATION: Falcon Research and Development Company; US Army Materiel Systems Analysis Activity.

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ABSTRACT: The US Army Materiel Systems Analysis Activity has conducted an effectiveness analysis of potential air-to-air combat involving helicopters. This paper will outline the techniques involved in this analysis, some of the general lessons learned as a result of the analysis, and some of the areas which must be investigated to strengthen future analyses of this topic.

The analysis considered aerial gun systems, various guided missile systems and rockets. The simulation used to provide the gun effectiveness results was the AMSAA Helicopter Air-to-Air Combat Simulation (HATACS) model. This is a digital, expected value computer simulation (coded in FORTRAN IV) of air-to-air gunnery between two helicopters. A brief description of this model will be included in the paper.

A time line analysis will be described in which the time required to bring the various forward firing weapons on target, to acquire and launch is established. In this analysis the relative position of the two helicopters at the outset of the engagement can be varied.

A brief description is given concerning tactics and evasive maneuvers for helicopters under attack. Also included are considerations of simple gunnery duels between helicopters.

TITLE: Investigations Into Air-to-Air Combat Between Helicopters

AUTHORS: Mr. James H. Young, Falcon Research and Development Company

Mr. Wyoming B. Paris, Jr., US Army Materiel Systems Analysis Activity

Introduction. The US Army Systems Analysis Activity has conducted a series of investigations into the effectiveness of helicopters involved in air-to-air combat. These investigations were concerned with aerial gun and missile systems for both friendly and enemy helicopters. A number of mathematical models have been developed to support the various analyses and these models will be briefly described in this paper. These models include simulations of helicopter flight paths, one sided engagements (one helicopter passive) and interactive duels between helicopters. A field test of helicopter maneuver simulation is described. Finally several proposed modifications to provide more realism in the simulation of air-to-air combat between helicopters will be discussed.

Concept of the Engagement. To date there is little information, real or theoretical, available on air-to-air engagements between helicopters. As a consequence of this scarcity of information, the following concept of such engagements has been developed. Encounters between helicopters will occur over all ranges, limited only by the effective ranges of the weapons employed. Some encounters will occur by chance while each helicopter is proceeding on its primary mission not related to air-to-air combat. The engagement ranges in this case will be short and of short duration with the helicopter which is at a disadvantage seeking cover to terminate the engagement or to seek a more advantageous set of engagement conditions. In other cases, particularly as the numbers of advanced attack helicopters increase, engagements with missiles and guns will take place at longer ranges.

Gun Analysis. The simulation of air-to-air gunnery between helicopters is accomplished by means of the Helicopter Air-to-Air Combat Simulation (HATACS) model. This model is a completely digital, expected value, computer simulation and is coded in FORTRAN IV. The purpose of the model is to evaluate various gun systems in the air-to-air role, analyze the feasibility of prospective helicopter target evasive maneuvers, and evaluate possible tactics of the attacking aircraft. Both passive engagements (where the target helicopter does not return fire) and duels between two helicopters can be simulated by the HATACS model and the DUEL sub-model. The simulation contains mathematical descriptions of the vulnerable portions of the target aircraft, as well as descriptions of simplified fire control, target maneuver, weapon system characteristics, and the geometry and kinematics of the aerial combat engagement. The measure of effectiveness employed for the passive engagement is the probability of target defeat. In the case of a duel between helicopters, the time history of defeat probability is provided for each helicopter.

The HATACS model computes the relative geometry and kinematics of the engagement with respect to a three-dimensional inertial space. Both the target and the attacker may be placed at any point within this

space at the outset of the engagement. Target and attacker kinematics can be handled several ways. First of all the target flight path may be generated by the model using one of three basic maneuvers or it may have a path of any form whatsoever which can be read-in to the model. Secondly, the attacker may have a path of pure pursuit generated by the model for any target path, or it may optionally be read-in to the model in the case where the target path is read-in. A total of three options jointly result for target and attacker flight paths: (1) a specific flight path generator can be selected for the target in response to which the attacking aircraft flies a pure pursuit path toward the target, (2) a target flight path is read-in against which the attacking aircraft flies pure pursuit, or (3) both target and attacker flight paths and time histories are read-in.

When the flight path generator option is selected, the target helicopter is considered to be flying straight and level at constant speed until the time the engagement commences. The target can fly one of three basic maneuvers upon receiving fire:

1. continue straight and level at constant speed (optional dive),

2. continue straight and level with constant acceleration or deceleration to a pre-defined speed (optional dive), or

3. execute a constant velocity turn toward or away from the attacker at a specified roll angle.

The attacker flies pure pursuit utilizing the off-axis firing capability of the turretted weapon system to accomplish target lead. The equation of this pursuit path is approximated in the model by a discrete lineal element process. In addition, the parameters of pursuit may be varied so that the attacker may conduct the attack from a hover, from constant speed pursuit or during an accelerated pursuit.

When the flight path read-in option is selected, a time history of aircraft position (x,y,z-coordinates) and orientation (roll, pitch and yaw angles with respect to the aircraft velocity vector) given at regular time intervals, must be provided for the entire engagement sequence. The model then uses these data to calculate the aircraft position, velocity, acceleration and orientation throughout the engagement. (In the event that aircraft orientation data are not furnished, the model sets yaw, pitch and roll angles to zero.)

The HATACS model currently approximates the target description by means of six, singly vulnerable, vulnerable areas. These vulnerable areas, adapted for the proper approach angle for the incoming rounds are represented by an exponential kill function (diffused target). The effects of either independent fire by bursts, or salvo fire can be calculated.

A particular gun system is characterized in the model by the specification of its firing rate, projectile trajectory characteristics, system errors, and firing doctrine. Range estimation error may be used also.

When a burst is fired by the attacking gunner, the line of fire should lead the moving target to account for the future position of the target at the time arrival of the rounds. The level of fire control, or more specifically, target future position prediction, has been parameterized in the HATACS model to provide three levels of future position prediction. These levels are:

(1) no prediction

(2) linear prediction, and

(3) perfect prediction.

"No prediction" and "perfect prediction" represent the lower and upper limits, respectively, of the gunner/weapon system capability to estimate the future position of the moving target helicopter. With "no prediction" the gunner centers his point of aim on the current target position, and no attempt is made to account for any change in the target's position during the time-of-flight of the bullet. With "perfect prediction" the gunner correctly assessed the target flight path at time of fire so that the center of the burst lies at the target center of vulnerability. "Linear prediction" is perhaps a more realistic model of the gunner/weapon system fire control, and will almost always produce a level of firing accuracy bounded by the previous two levels. Linear prediction involves the gunners assumption that the target will continue in a linear path at its observed speed and in a direction determined by the true course angle and climb angle at the time of fire. Using this assumption, it is possible to predict an intercept point for target and projectile and then calculate the required lead angle to account for target movement during projectile time of flight. If the target actually flies at constant conditions from time of fire, the prediction and corresponding lead angle generated by the model will be the same as they would be in the case of perfect prediction. However, if the target helicopter executes any type of maneuver during the time of flight of the projectile, then the total system error will likely contain an additional component of error (a bias). This lead bias is measured by the length of the projection, onto the plane perpendicular to the line of fire, of the line between the actual position of the target and the predicted position of the target. The lead bias error actually represents the inability of the gunner to accurately predict target future position during helicopter maneuver.

Aim and ballistic errors are required by the model as a part of the weapon system description. Since turretted guns are simulated by the model, the aiming errors must be provided as a function of off-axis firing angle. They may also be exercised as a function of range to the target.

An air-to-air engagement will be terminated when one of the following conditions is satisfied:

- A specified number of bursts have been fired,
- The defeat probability exceeds a specified level,
- The separation range drops below a specified break off distance,

- One of the aircraft drops below a specified minimum altitude (analogous to going into masking), or
- The gun turret limits of the attacking aircraft are exceeded.

When a gunnery duel between two helicopters is to be simulated, two sets of preliminary calculations by the HATACS model are currently required. In each calculation the engagement conditions of the duel are simulated in all respects except one. In the first calculation only one of the two helicopters is firing its guns. In the second calculation, only the other helicopter is permitted to fire. In this manner the time history of conditional single burst probabilities of target defeat is obtained for each helicopter. The condition applied is that the burst is fired by an undamaged helicopter. At this point, these probability time histories provide input for the DUEL sub-model of HATACS. Each time history provides the time of fire of each burst, the time at which each burst arrives at its target, and the resultant probability of target defeat. An additional input for DUEL is the firing sequence to be simulated for the adversaries. The various time histories for the duel are then imposed on a master clock in DUEL. During the duel, each burst fired is appropriately reduced by the probability that the firing helicopter has survived the duel to the time point at which the burst is fired. The output of the DUEL sub-model contains, for each helicopter, the time history of the cumulative probability that the helicopter is defeated in the duel.

Specific references for investigations by AMSAA into air-to-air gunnery involving helicopters are contained in the Bibliography.

Missile Analysis. In the investigation of helicopter employment of fixed, forward-firing, guided weapon systems in air-to-air combat, two principal times are of interest. The first time is the time to maneuver the attacking aircraft into a position from which the target is acquired by a sight or missile sensor. The second is the time necessary to meet some condition required to reliably launch the missile, an example would be time to obtain lock-on by an IR sensor.

The time to bring the attacking helicopter into position to acquire the target with a forward-firing weapon system can be subdivided into three time intervals:

- the pilot reaction time, i.e., the time from detection, required by the pilot to analyze the situation, select his maneuver and activate the controls,
- the system reaction time, i.e., the time between activation of controls and aircraft reaction, and
- the time from aircraft reaction to alignment of the nose of the aircraft on the target.

The pilot reaction time and the aircraft response times have been so far assumed to be independent of the relative position of the attacker and the target. On the other hand, the time to accomplish the maneuver depends strongly on the relative orientation of an attacker and target.

The description of such maneuvers is the object of a supplementary flight path generator model called TRANROL which has been recently developed independently of the HATACS model. This model can supply flight input to the HATACS model for use in the read-in option. TRANROL uses a combined pilot and system reaction time as an input together with the initial position of the attacker with respect to the target. After the response time has elapsed, the aircraft rolls into a turn, continues to increase the roll angle up to a specified value, maintains this roll angle and then rolls out on target. The model also contains an option which permits the attacker velocity to decelerate and then accelerate back to initial speed during the turn. The turn maneuver is accomplished in the model by a number of small discrete time steps within which roll angle and aircraft speed are constant. These values are changed appropriately from step to step to simulate the continuous motion of the aircraft in the turn. The target is assumed to be flying straight and level at constant speed.

The time required for the guidance system of the missile to achieve launch conditions, once the attacker has aligned with the target, is dependent upon the physical nature of the specific system and, under certain conditions, range and aspect to the target. The computer model has two options with which time from "acquire" to "launch" can be treated. These options are:

- input fixed time to launch, or
- input tables which give time to launch as a function of range and aspect to the target.

Under either of these two options it is possible to generate a time line analysis from target detection to launch for any particular initial orientation of attacker and moving aerial target. If launch conditions can not be met in a particular engagement, under the second option, this information will be so stated in the program output. Terminal effectiveness of a launch is not now a part of the simulation.

Figure 1 illustrates the time line characteristics for a typical encounter which can be simulated by this procedure. A possible application of this model might occur when weapons systems of different characteristics are being compared for air-to-air applications, e.g., when a more potent forward firing system is being compared with a system which can be fired off-axis.

Field Test of Helicopter Maneuver Simulation. Several flight path generators have been mentioned which were developed to support the HATACS model and the missile time line analyses. These computer sub-models, or subroutines, are not engineering models in the sense that detailed aerodynamic characteristics of helicopters are not reflected in the simulation of helicopter flight paths. The approach taken is that of kinematic motion of a point mass under specified velocity and acceleration conditions along pre-defined analytic expressions for the desired flight path (straight line flight, dives, and circular turns). In the current version of HATACS circular turns at constant g-load can be generated and the fixed roll angle is determined. For the missile time line analysis, the TRANROL flight path generator model was created which permitted transitional

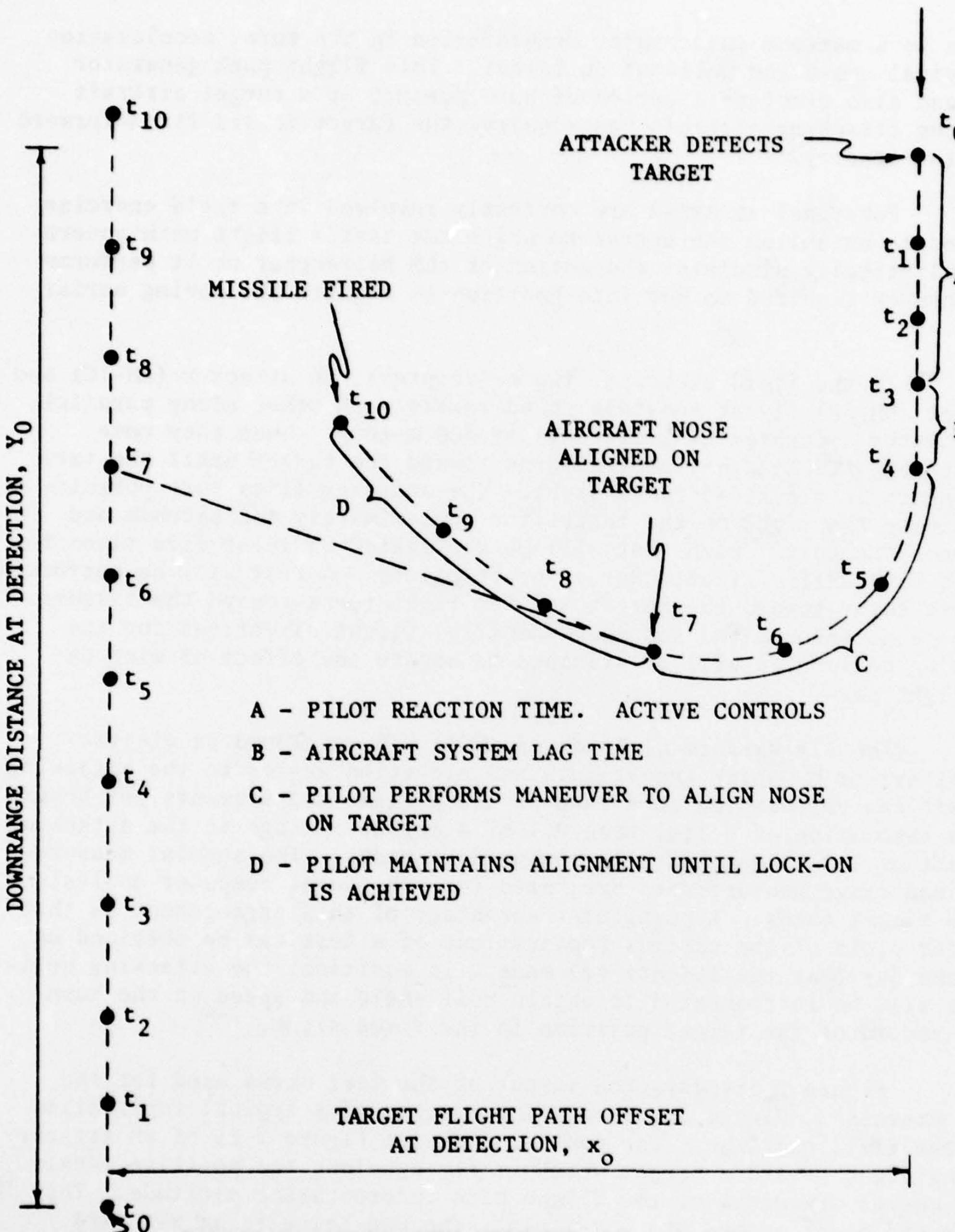

FIGURE 1 TIME LINE CHARACTERISTICS OF A TYPICAL AIR-TO-AIR ENCOUNTER INITIATED FROM A FLY-BY SITUATION (ATTACKER DETECTION TIME ADVANTAGE)

roll-in to a maximum roll angle, deceleration in the turn, acceleration to original speed and roll-out on target. This flight path generator model can also simulate a period of pure pursuit of a target aircraft after the attacking aircraft has acquired the target in its fixed forward sight (or sensor).

Personnel at AMSAA are currently involved in a field exercise designed to establish the degree to which the latter flight path generator realistically simulates the motion of the helicopter as it performs the maneuver required to get into position to acquire the moving aerial target.

In the field exercise, two helicopters, an attacker (AH-1G) and a target (OH-58) fly at constant speed toward each other along parallel flight paths separated by a distance of 400 meters. When they come abreast the attacking helicopter turns toward the target until the target appears in a fixed-forward sight. The attacker flies pure pursuit maintaining the sight on the target for approximately ten seconds and then ends the test. Each test will be replicated at least five times for each of five different attacker aircraft pilots. A test will be performed for left turns toward the target and for right turns toward the targets. Alternate northbound and southbound initial flight directions for the attacking helicopter will be examined to negate the effect of wing on the flight path.

The Air Warfare Division of AMSAA has developed an electro-optical system by which the azimuth and elevation angles to the attacking aircraft can be measured at a rate of about eight measurements per second with a resolution of better than 0.1 of a degree. Range to the attacking aircraft on its flight path is measured by radar. The angular measurements and range measurements are taped for subsequent computer analysis of the flight paths. A particular advantage of this arrangement is that computer plots of the various replications of a test can be obtained on the same day that the flights are made. In addition, the attacking helicopter will be instrumented to obtain roll angle and speed in the turn and a record of the target position in the fixed sight.

Figure 2 displays the layout of the test arena used for the field exercise. Figure 3 presents the results of a typical replication from the field exercise. The central curve of Figure 3 is of an attacker turning right toward a target which is flying along the positive x-axis. Other curves are plots of the flight path incorporating altitude. The one on the right represents a y-z plot, the one below is an x-z plot.

Actual flight path are complexly determined real world events. On the other hand the simulated flight paths produced by TRANROL require but five specific pieces of information as input. These are

- rate at which aircraft rolls in and out of turn,
- maximum roll angle in turn,
- speed at beginning of turn,
- speed change within the turn, and

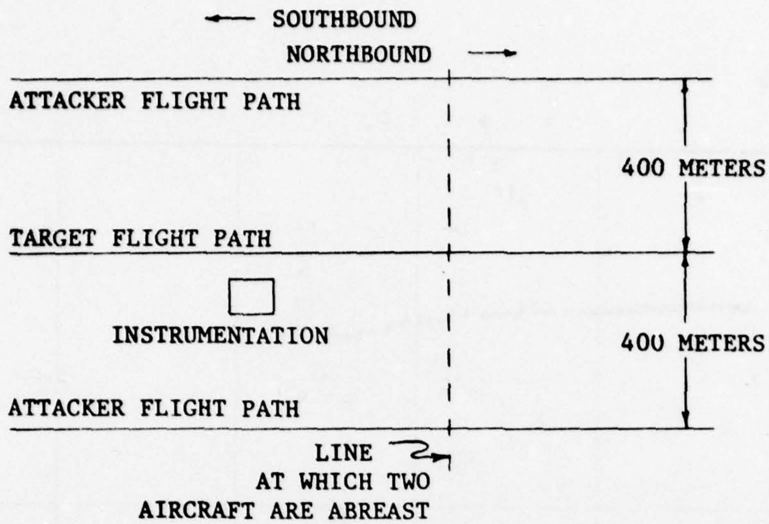

FIGURE 2   FIELD EXERCISE LAYOUT

- relative position of attacker and target.

For a specific helicopter type, these data can be obtained from aerodynamic models of helicopter flight characteristics. Prior to the completion of the field exercise a flight path will be generated by the TRANROL model, based on theoretical input data, for comparison with the field data. In addition, flight paths will be generated using roll angle and speed data obtained in the field exercise.

Future Efforts. As the AMSAA investigations into air-to-air combat between helicopters proceed, it is anticipated that the lessons learned will lead to modifications in the HATACS model and to the generation of additional computer models to add more realism to future simulations.

At this time a number of modifications have been proposed for the HATACS model. These modifications involve:

- modeling the vulnerable components of the target helicopter,
- providing for multiple helicopter damage levels (attrition, forced landing, mission abort),
- replacing constant g-turn flight path generator with TRANROL model, and
- increasing the number of target evasive maneuvers, e.g., diving turns and s-turns.

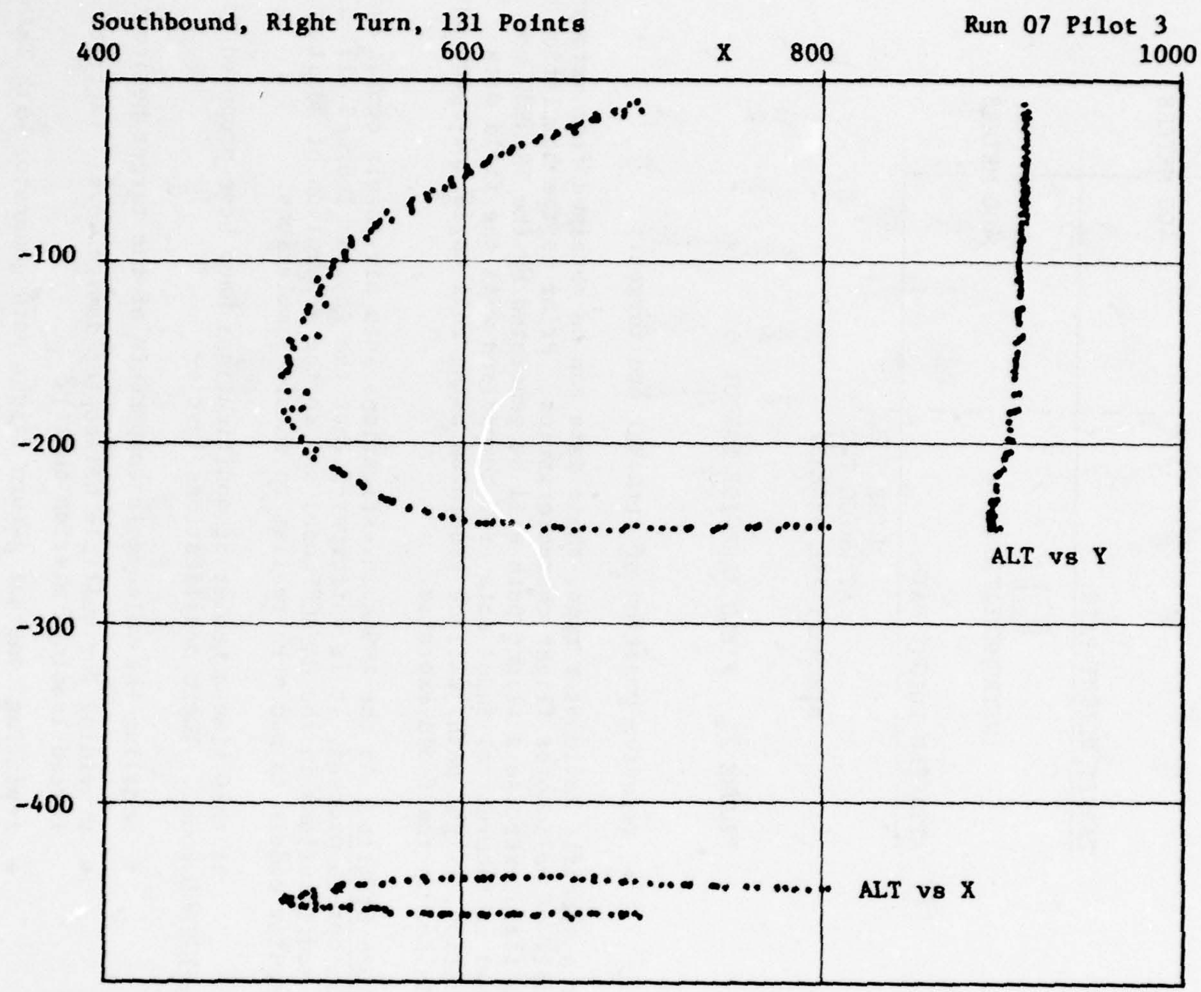

FIGURE 3 TYPICAL RESULTS FROM FIELD EXERCISE

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TITLE: Combat Engineering and Combat Engineering Analysis--Prospects, Promises, and Progress

AUTHORS: Mr. Gerald E. Cooper and MAJ Terry W. Curl, US Army Engineer Studies Group (ESG)

ABSTRACT: The paper provides an overview of completed and on-going work in combat engineering analysis. The mid- and longer-range implications of four ESG papers are summarized:

-- Measuring Obstacle Effectiveness--A Fresh Perspective.
-- Military Bridging in the 80s and Beyond--a Glimpse into the Future.
-- Battlefield Obstacles--An Appraisal of the State of the Art in Measuring Obstacle Effectiveness.
-- On the Relation of Combat Engineering (and Combat Engineering Analysis) to Mobility/Countermobility and Survivability for Defensive Operations.

Progress on the on-going "Operational Effectiveness of Obstacles" is discussed. Reference is made to continuing effort to develop an estimate of wartime combat engineering requirements of the V (US) Corps in Europe. The paper does not attempt to provide the last word on all combat engineering; instead it offers several suggestions about directions that combat engineering analysis in particular and combat analysis in general must take to best exploit combat engineering for tomorrow's Army.

TITLE: Combat Engineering and Combat Engineering Analysis--Prospects, Promises, and Progress

AUTHORS: Mr. Gerald E. Cooper
MAJ Terry W. Curl

AGENCY: US Army Engineer Studies Group (ESG)

INTRODUCTION

Combat engineering is concerned with mobility, countermobility, survivability, and general engineering on the battlefield. As necessary, the Engineers also are required to fight as infantry. The Engineers were declared a combat arm in 1975. Many changes are forcing new thought about current and future combat engineering requirements and capabilities.

Over the years combat engineering emphasis has shifted among the mobility, countermobility, survivability, and general engineering roles. ESG studies reflect these differences in emphasis. Some past studies emphasized mobility with little or no mention of other roles. Some other studies have been devoted mainly to countermobility. Fortunately, there have been times when from two to all the roles have been addressed together. This paper addresses some recent examples of ESG studies, identifies some of their key points, and tries to integrate their concepts into a modest overview of combat engineering and on-going combat engineering analysis.

EXAMPLE STUDIES

Four recent examples have been chosen and are covered in chronological order:

a. Measuring Obstacle Effectiveness--A Fresh Perspective. This paper, published in March 1975, emphasizes the countermobility role in enhancing a defender's direct fire weapons effects. It introduced the notion of preferred range/time windows for the engagement of attacking weapons.

b. Military Bridging in the 80s and Beyond--A Glimpse Into the Future. As the name suggests, this paper (published in May 1976) is involved primarily with mobility. It is of interest here for some of the questions it raised with regard to the treatment of battlefield uncertainty and criteria of mission success.

c. Battlefield Obstacles--An Appraisal of the State of the Art in Measuring Obstacle Effectiveness. This paper of September 1976 is largely a compendium of the frustrations met in trying to quantify what many people regard as obvious and others deny. The primary focus is on countermobility, but much is suggested about possible relations to other roles and activities. The paper also suggests ways to overcome some of the problems involved in measuring obstacle effectiveness.

d. On the Relation of Combat Engineering (and Combat Engineering Analysis) to Mobility/Countermobility and Survivability for Defensive Operations. This November 1976 paper only appeared in draft. It reports the results of some hasty analysis to prioritize mobility, countermobility, and survivability in the tight interval D-1 to D+1.

A SNAPSHOT OF UNCERTAINTY

Consider the results of a simplified obstacle-free duel based entirely on data from unclassified sources. Figure 1 shows the survivors of 15 independent simulated trials in which exchange began at 2,000 meters. One view might be that the 15 trials represent replications over exactly the same position. This is a useful and interesting viewpoint giving some insight to likely uncertainties. Another view might be that the same trials represent activity in 15 adjacent positions all part of the same larger battle. The outcome in either view is discouraging to the defenders, few of whom even survive to be discouraged. But, as poorly as the defense does overall, there are four positions in which the attackers are annihilated--a little defender sunshine on an otherwise dreary day. This sort of variation from position to position is just the sort of result that makes us wonder about the impact of small-scale uncertainty on larger scale outcome. We could consider a different set of duels in which the defenders did very well on the average but in which some few positions suffered very badly. Except when the numbers are overwhelming for one side or the other, there is almost always this spottiness in the small-scale outcomes. It was this sort of observation that led us to think that combat engineering should be analyzed not just for how it can influence average results but for how it can affect variations about the mean, particularly to guard against unfavorable variations from the mean.

THE "SAME" DUEL REPLICATED

INITIAL STRENGTHS...	DEFENDER		ATTACKER	
	ITV	3	T62	8
	M60A1	1		
	DRAGON	1		

INITIAL EXCHANGE @ 2,000 METERS

SURVIVING STRENGTHS...	DEFENDER			ATTACKER
TRIAL	ITV	M60A1	DRAGON	T62
1	2	0	0	0
2	1	0	0	1
3	2	0	0	0
4	2	0	0	5
5	1	0	0	0
6	2	0	0	0
7	0	0	0	5
8	0	0	0	5
9	2	0	0	0
10	0	0	0	3
11	0	0	0	6
12	0	0	0	1
13	0	0	0	5
14	2	0	0	1
15	0	0	0	1

Figure 1

THE PRIMORDIAL AND LATER BATTLE ANALYSIS

In the beginning of analysis things were delightfully simple. There were attackers and there were defenders. Each could only be alive and well or disabled or worse.

Figure 2 is hardly the last word in anything, unless it be over-simplification. Yet, it can serve to illustrate several useful notions. Let us imagine that each rectangle is actually a small box. Let us also imagine that different colored counters represent the combatants. During an engagement, the counters move around a great deal from box to box. The movement of any particular counter may be greatly influenced by the position and movement of many other counters, both friendly and enemy, especially enemy.

A PRIMITIVE VIEW

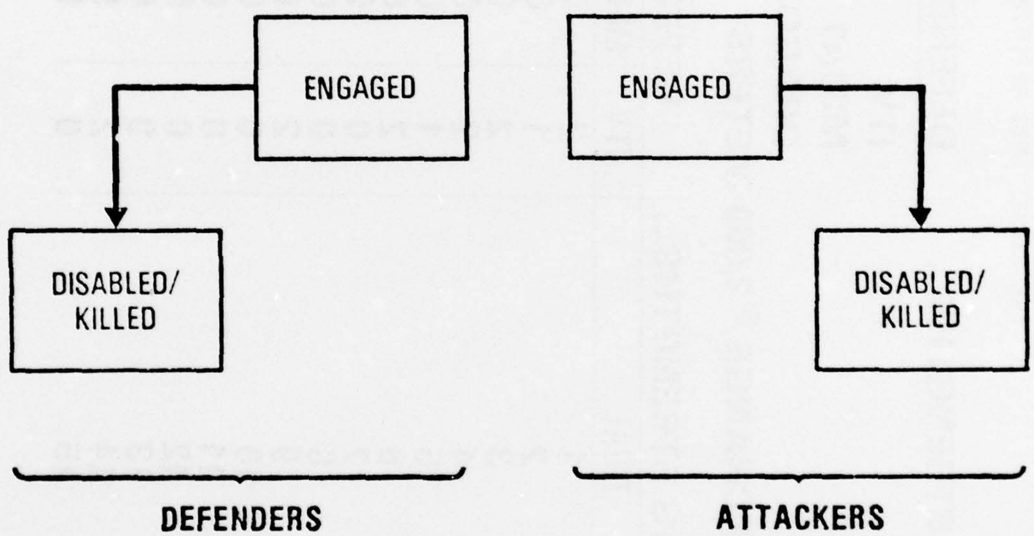

Figure 2

Given some initial number of defenders and attackers in their corresponding engaged conditions, analysts speculated about how the antagonists made the transition to disability or death. They argued about whether the transition rates depended on the number of occupants in the engaged boxes and, if so, about the form of that dependence. Some analysts felt uncomfortable with the simplicity of this categorization scheme and argued for generalizations representing a richer variety of conditions. Why? Because it was supposed that differences in the condition of the antagonists influenced subsequent events and that the mix of conditions changed over time. No one may have ever believed that all surviving antagonists were actually "engaged" throughout an "engagement." However, retaining such a simple categorization scheme would imply that the survivor segment in different conditions remained the same or was immaterial. Yet, if everything else remained the same, how was one to explain the variability among real or simulated engagements? Efforts to explain such differences have led us and others to consider, sometimes separately, sometimes together:

- Hazards in deploying to the scene of action.
- Differences in range.
- Changes in visibility with position or time.
- Differences in protective cover and surroundings.
- "Engagement" of disabled/dead targets or decoys.
- Temporary or permanent dysfunction at or around obstacles.
- Variations in suppression.

These imply a wider variety of conditions to be considered for weapons and people. They also imply a frequently changing number of directly engaged weapons and people. That can be very important.

Figure 3 shows the most enriched framework considered in this paper. Each of the two original engaged blocks has been generalized to include new blocks. Again, the idea is that defender and attacker counters move from block to block, in some cases back and forth among the same blocks. Without getting specific, we can suggest that the flow of counters among blocks depends on the number of counters occupying the different blocks...whether we are thinking about real battles, table-top encounters, differential equations, computer simulations, or day-dreams. This modest framework is sufficient to relate the already mentioned ESG studies and on-going work.

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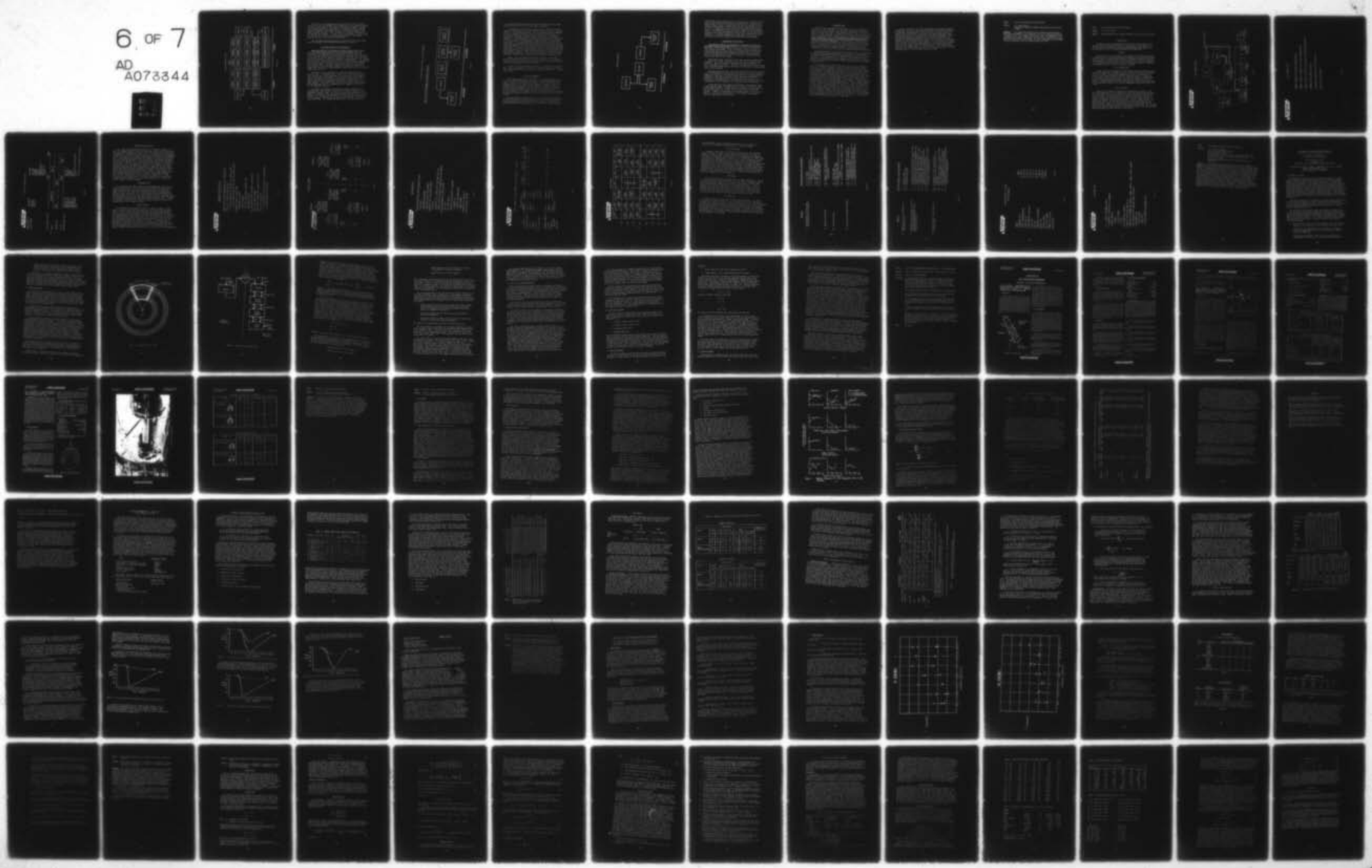

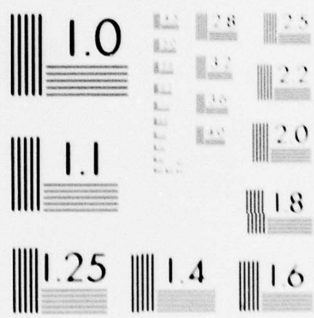

MICROCOPY RESOLUTION TEST CHART
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A LESS PRIMITIVE VIEW

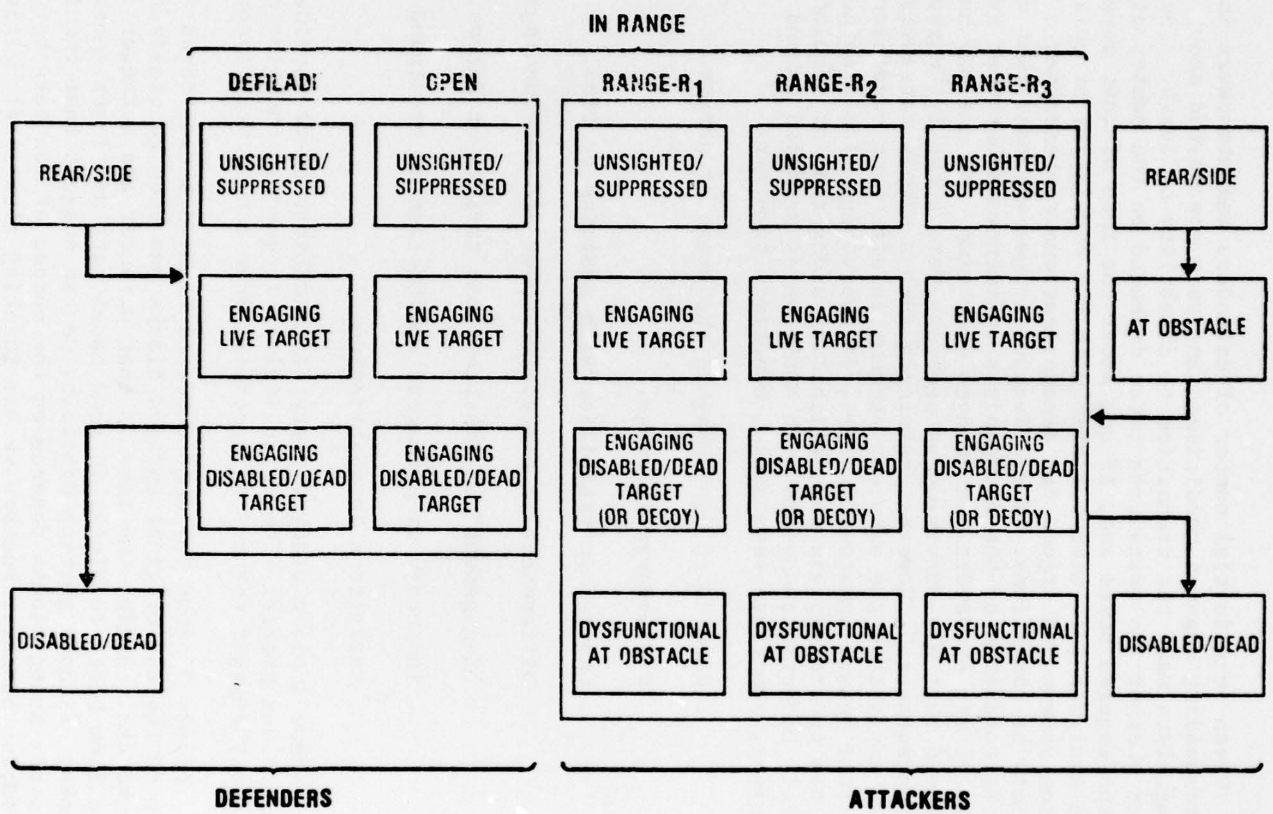


Figure 3

Now, if we are interpreting our own work and the work of others correctly, we must be impressed by the importance of occupancy variations for the different boxes. Very short-term variations cannot be ignored. Some momentary change may swing short- and long-term results from one extreme to another. The general process may be highly unstable, with highly variable outcomes. This, we think, has different implications for attacker and defender. To some extent, the defender is like a chain; the defense may be no better than its weakest links. The attacker, however, may be as good as his few best probes.

The ESG papers mentioned earlier are described below in the framework of conditions and transformations depicted in Figure 3.

THE FRESH PERSPECTIVE IN RETROSPECT

Measuring Obstacle Effectiveness--A Fresh Perspective introduces attacker condition/activity states at different ranges. While it incorporates some sensitivity to line-of-sight and ballistic variations, the paper emphasizes the variation of range with time. The spirit of the paper is much as suggested in Figure 4. However, range variation with time is limited to that of a formation moving together. The counters may die anywhere, but the survivors move as a compact whole. The surviving attackers are neither permitted nor forced to split into subformations at different ranges. The paper suggests that outcomes could be made more favorable to the defender by obstacles delaying the attacker at ranges where the relative range-dependent characteristics of the defender's weapons are superior.

The idea is to put attackers in a preferred range window for a preferred time. That suggestion is liable to the caution that delay of that sort may put so many attackers in the window that the defenders cannot engage them fast enough. Hence, such an obstacle may backfire. Without the obstacle, there is the hazard that attackers may close faster than they can be disabled or destroyed by the defenders' long-range weapons. The obstacle under many expected threat conditions can help prolong that part of an engagement at the ranges more favorable for the defenders' weapons.

In tightly controlling the variation in range, the defense may introduce some less favorable variations in attacker strength at the supposedly favorable range. We have noted that some simulations do not permit the attacker to fire beyond the "maximum effective range" of his weapons. If this range is less than the distance between the defender and the obstacle, the obstacle may appear extra effective and artificially one-sided. It is worth noting, however, that the massed fires

THE RANGE GENERALIZATION--ATTACKER MOVEMENT

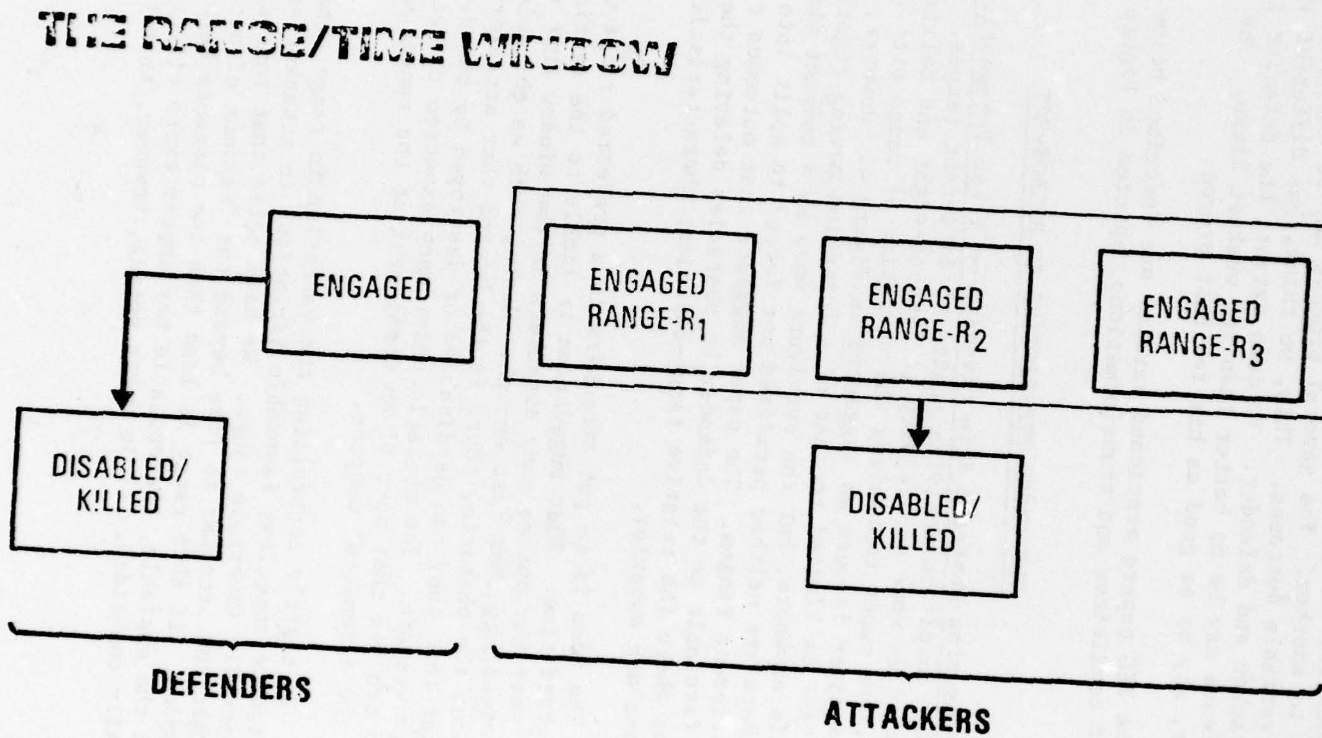


Figure 4

of many tanks from beyond their individually maximum effective range can be very destructive or at least highly suppressive.

The obstacles in the Fresh Perspectives paper were notionalized; their only operational effect was a short-term interruption to attacker advance. It was assumed, however, that the obstacle had been emplaced to provide maximum visibility from the defenders' position(s). In this sense, the obstacle tended to reduce the number of unsighted combatants. That paper did not address another potential hazard to the defense. It did not consider the potential distraction and confusion in concentrating live and disabled or dead attackers in a relatively small area. It is conceivable that the defense might find more of its weapons engaging disabled or dead attackers than live targets clustered around the obstacle. A better obstacle might have some properties other than delay. For example, some obstacles can directly inflict casualties. Some obstacles force or encourage the attacker to divert attention from the defender's weapons, thereby increasing unsighted attackers but not unsighting the defenders. Some types of obstacles can make an attacker temporarily dysfunctional without actually disabling or damaging him.

Figure 3 could have been generalized to include a much wider variety of possible conditions in or around obstacles. For example, it does not introduce different psychological states although some studies outside ESG are emphasizing crew reactions.

No one ever said the complete analysis of countermobility would be easy. One of our targets is to write a new paper sometime in the next year--"Measuring Obstacle Effectiveness--A Mature Perspective." It will not be easy.

A TOUCH OF MOBILITY

The bridging paper mainly addresses flow of defender elements from the rear or side to assure that the number of defenders engaging live targets could be made and kept sufficient. Figure 5 shows the corresponding subset of the general block diagram; it suggests a need for counters to flow from rear or side to engaged. This paper does not address rearward movement to any great extent; however, it does note that high attrition environments may imply heavier rearward flow of unserviceables if the forward flow of serviceables is to be sustained. Moving heavy unpowered equipment across gaps can introduce some special problems.

The major analytic problem encountered is interesting because it surfaces repeatedly in different guises. We find that most discussions of bridging mission success directly equate percent of success with percent of gaps that could be crossed. Crossing 9 of 10 gaps allegedly

DEFENDER MOVEMENT

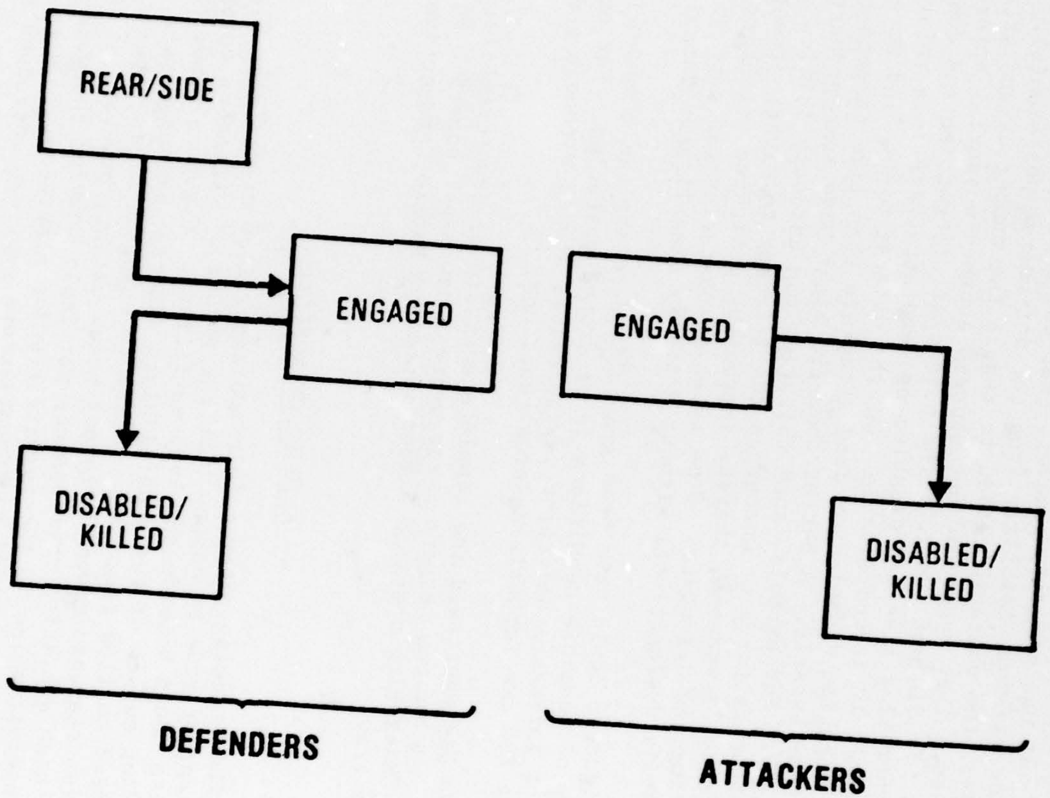


Figure 5

produced 90 percent mission success. We point out the inherent differences between single and multiple route requirements. Regarding the single route as a chain, the analyst notes that a single gap too long among many gaps becomes a weakest link and may drive mission success to zero. In contrast, for six parallel routes perhaps only three or four of six columns need arrive to achieve complete or nearly complete success. The discussion sounds more like a debate on the comparative reliability of series and parallel circuits than a treatise on tactical mobility. It certainly emphasizes the importance and difficulty of estimating success when dealing with combinations and sequences.

COUNTERMOBILITY REVISITED

Battlefield Obstacles--An Appraisal of the State of the Art in Measuring Obstacle Effectiveness collects a variety of thoughts about measuring or demonstrating the effectiveness of battlefield obstacles, natural and manmade. After considering historical records and several approaches to combat analysis, the paper notes that obstacle effectiveness measurement has remained primitive and unconvincing. Part of the difficulty is traced to limitations in representing and interpreting obstacle-free combat.

Among other points, the paper argues that too many representations of obstacle-free combat consider too few conditions of attackers and defenders. Many of the ignored conditions are deemed important to short- and long-term results. Therefore, any model that does not include such conditions becomes suspect as a means for analyzing or demonstrating obstacle effectiveness.

The paper speculates that some useful obstacle effects may have more to do with reducing variations about some mean value than with changing a mean value directly. The speculation extends to the suggestion that managing or conditioning variations about some mean should sooner or later lead to new opportunities to change mean values as well. A corollary to the speculation is that expected-value combat formulations, by definition, do not represent these possibly critical subtleties.

In the year since the lament was published, an encouraging number of agencies have added some theoretical and empirical evidence to the countermobility debate. Though certainly relevant, the new evidence is not yet sufficient. We can take little if any credit for the new evidence. Rather, the invention of scatterable mines is forcing more people to think about countermobility. Individually and combined, all the combat arms must add evidence.

A BROADER VIEW

Mobility and countermobility each might fully occupy different analysts for their lifetimes. At some time, however, it becomes necessary to let the different combat engineer roles compete. The last paper considered here takes a broader view than the first three but stops short of a total overview. Indeed, there are limitations to both the scope and approach used for On the Relation of Combat Engineering (and Combat Engineering Analysis) to Mobility/Countermobility and Survivability for Defensive Operations. The main object of the paper is to prioritize mobility, countermobility, and survivability for defensive operations in 1985 Europe from D-1 to D+1--a key segment of the first battle. The approach is to consider weapon hit/kill characteristics and terrain as principal combat influences. Quantitative data are considered, but largely as ratios and in simple scratchpad calculations.

After having given so much attention to mobility and countermobility in the months preceding that analysis, we decided that survivability outranked countermobility and that countermobility outranked mobility in importance. And, impressed by the volume of attacker fires and the difficulty of suppressing them, we suggested that deception be inserted between countermobility and mobility though not necessarily as a combat engineering role.

One feature of this view is that there are few if any universal rules. The combatants generally try to influence transitions among their own and their opponent's conditions. What is a good move in one circumstance may be unnecessary in another case and an outright mistake in yet another. In particular, the relative strengths are critical. The side with overwhelming strength need not shunt opponents into some unsighted, diverted, or dysfunctional condition before dispatching them to the great beyond. Up to some threat level, the defender need do nothing special to condition attackers. For example, obstacles may not contribute much until a certain threat exists. However, combat engineering may become critical as the threat increases. At even higher threat levels, no amount of combat engineering may be a sufficient addition to or multiplier of defense weapons. We can be sure that somewhere, sometime the defense and/or attacker will do something that varies from the expected, however defined. Given our concern that the defense is as weak as its weakest links and the attack as strong as its few strongest points, it should not be hard to understand our motive in trying to make combat engineering control or minimize such variations. Just how much is enough quantitatively remains less than clear.

Notice that none of the papers referenced here addressed general engineering. Amazingly, general engineering is often taken for granted by supporters and supportees. There are several efforts underway to remedy that situation and to bring all four combat engineering roles into perspective with one another and with systems in general. ESG is a participant in many of these efforts. We are now analyzing the totality of combat engineering in V (US) Corps and expect to turn our attention to VII Corps in the near future. In a more abstract, riskier vein, we continue trying to pump substance into the notions of obstacle effectiveness. ESG is also participating in the combat engineering project of the TRADOC Family of Systems Studies. All current projects mentioned are ambitious in scope and approach and should lead to useful, exciting results to be reported at some later AORS.

TITLE: Division Restructuring Study Program

AUTHOR: Dr. Virgil Henson
Training and Doctrine Command Combined Arms Test Activity (TCATA)

ABSTRACT: This paper describes the test program for Restructured Division with emphasis on the Battalion Test to be conducted beginning in October 1977. The purpose, objectives, scope, instrumentation, and schedule are included. Examples of the data to be collected are given. This field test will be the largest test ever conducted using instrumentation to provide hit and kill data in near real time.

TITLE: Division Restructuring Study Program

AUTHOR: Dr. Virgil Henson

AGENCY: Training and Doctrine Command Combined Arms Test Activity (TCATA)

INTRODUCTION

Elsewhere in these proceedings Colonel Don Pihl's paper outlines the concepts for the Restructured Division. The purpose of this paper is to describe the test program for the Restructured Division with emphasis on the Battalion Test to be conducted beginning 16 October 1977.

PURPOSE

The purpose of the test program is to evaluate the combat effectiveness of organizations of the proposed Restructured Heavy Division and to provide field test data to support appropriations, simulations, analysis, and evaluation efforts by other agencies. The results will assist in the comparison of the Restructured Division as currently structured in order to determine and recommend the most effective division structure.

TEST ORGANIZATION

Figure 1 depicts the organization for testing and the command relationships which have been established for the purpose of this test. Note that the test director, the III Corps Commander, has all of the elements required for test and evaluation under his immediate control. In addition to the forces required, the two divisions and the support, TCATA has been placed under his operational control for this test. Note also that he reports to TRADOC and that both the Combined Arms Center and the Operational Test and Evaluation Agency will conduct independent evaluations of the test results.

TEST OBJECTIVES

There are six major test objectives as indicated in Figure 2. The first four objectives will be examined in detail during the Battalion Phase. The fifth objective as well as the first four will be covered during the Division Phase. The sixth objective, Training Implications, has been the subject of data collection beginning the first of July, 1977, and will continue throughout the entire test program. Figure 3 summarizes the test and analysis plan. It indicates the units to be tested during both test phases and the schedule for restructuring as well as test dates and in-process reviews. This plan covers only the field test portion. The Combined Arms Center and the Operational Test and Evaluation Agency may continue their analyses beyond the time indicated in the figure.

TEST ORGANIZATION

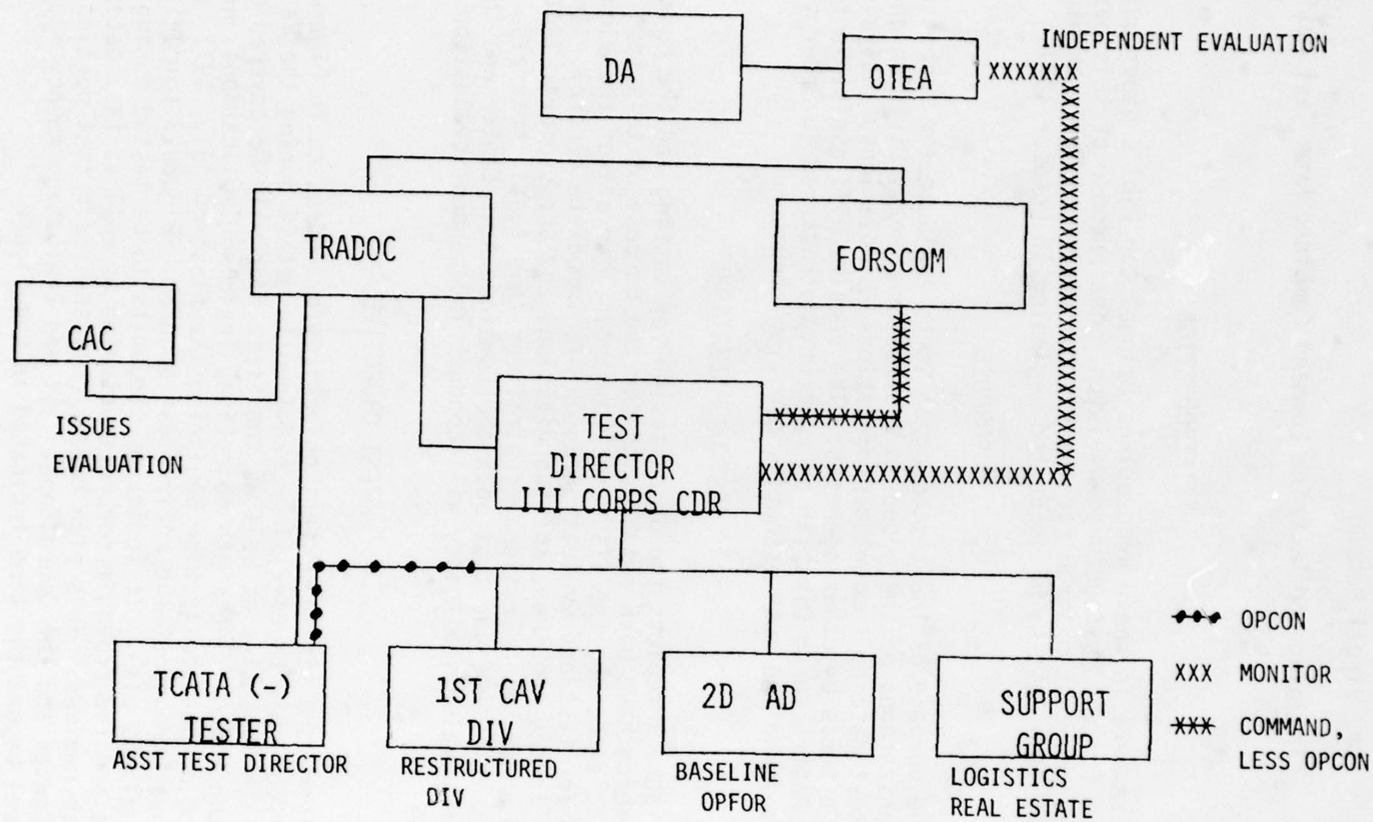


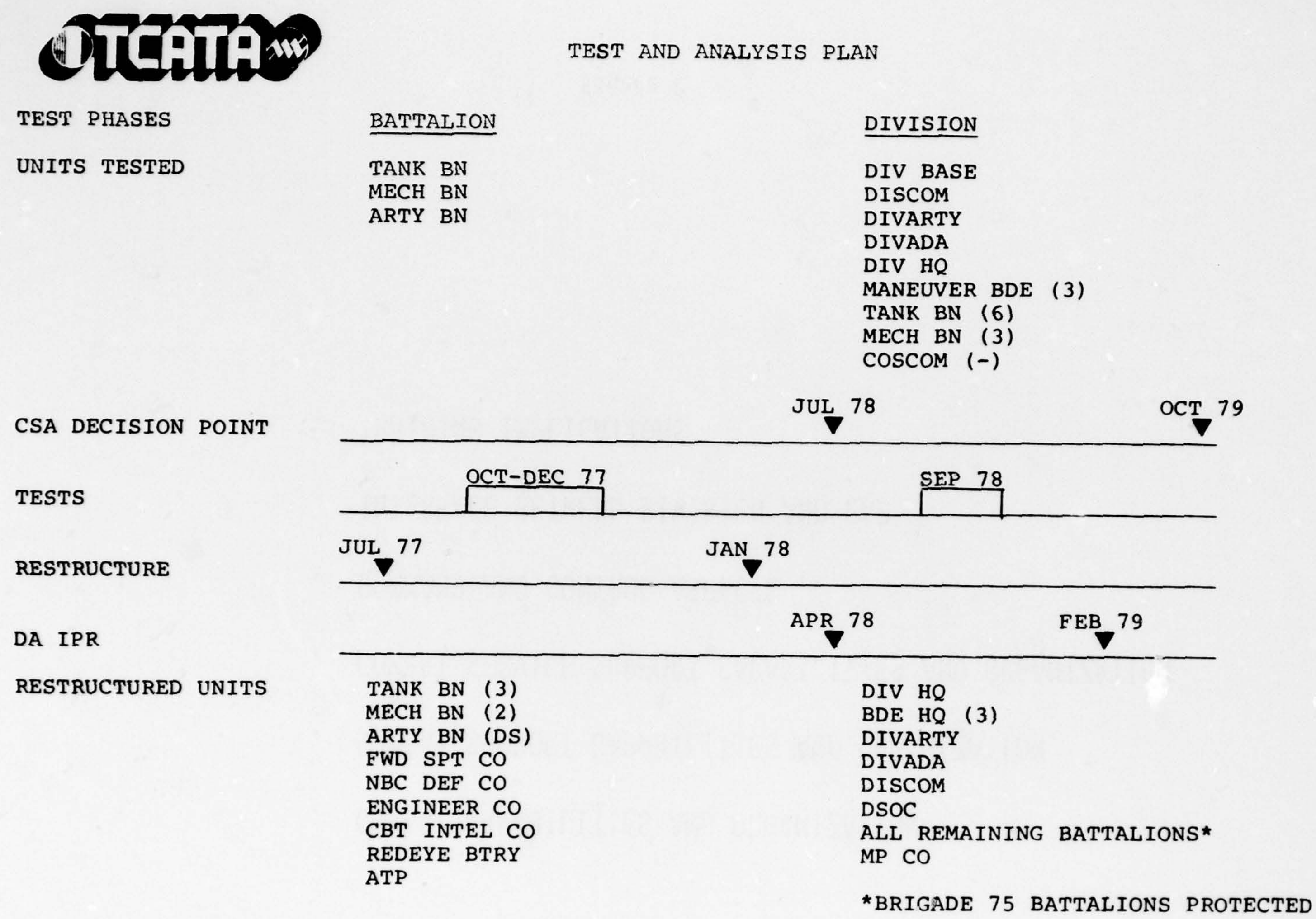
Figure 1

TCATA

TEST OBJECTIVES

- COMBAT CAPABILITIES AND ORGANIZATION
- COMBAT SUPPORT CAPABILITIES AND ORGANIZATION
- COMBAT SERVICE SUPPORT CAPABILITIES AND ORGANIZATION
- COMMAND AND CONTROL ASPECTS
- INTERFACE BETWEEN DIVISION AND EAD
- TRAINING IMPLICATIONS

Figure 2



TCATA
TEST AND ANALYSIS PLAN
TEST PHASES
BATTALION
DIVISION
UNITS TESTED
TANK BN
MECH BN
ARTY BN
DIV BASE
DISCOM
DIVARTY
DIVADA
DIV HQ
MANEUVER BDE (3)
TANK BN (6)
MECH BN (3)
COSCOM (-)
CSA DECISION POINT
JUL 78
OCT 79
TESTS
OCT-DEC 77
SEP 78
RESTRUCTURE
JUL 77
JAN 78
DA IPR
APR 78
FEB 79
RESTRUCTURED UNITS
TANK BN (3)
MECH BN (2)
ARTY BN (DS)
FWD SPT CO
NBC DEF CO
ENGINEER CO
CBT INTEL CO
REDEYE BTRY
ATP
DIV HQ
BDE HQ (3)
DIVARTY
DIVADA
DISCOM
DSOC
ALL REMAINING BATTALIONS*
MP CO
*BRIGADE 75 BATTALIONS PROTECTED

Figure 3

MANEUVER BATTALION TEST

The scope of the Maneuver Battalion Test is shown at Figure 4. It will be a comparative test with the performance of the current battalion's task force being compared to that of task forces which used restructured organizations. Although the sample size for the battalions to be compared is small (2 each), we will have an opportunity to contrast the performance of six line companies and eighteen line platoons for each type organizatio Note also that all battalions will participate as both player and aggress In order to accomplish this, a round robin scheme, depicted at Figure 5 will be used. The first task force will be tested during a 3-day period, during which it will be opposed by elements of up to three task forces acting as aggressor (the units when acting as aggressor will be highly controlled and will present formations and target array similar to those Warsaw Pact nations would be expected to present). At the end of the test period, the first battalion becomes a portion of the aggressor force and a second battalion task force is tested. This process continues until all four battalion task forces have been subjected to a 3-day test period. Instrumentation, a description of which is offered later, is then switched from the first set of four battalions to a second set and the process is again repeated.

INSTRUMENTATION

The Battalion Test relies heavily on instrumentation, not only to produce comparative attrition data but to insure that the forces on both sides "play the game." The forces involved in the test will be the largest that have ever been instrumented with hit/kill instrumentation that operates in near real time. A description of the instrumentation system is shown at Figure 6. Only main armament (tank main guns and anti-tank guided missiles) will be simulated during this test. The total number of instrumented systems will reach 118 during the field trials. A sample of the forces involved and the number of systems that will be fully instrumented by trial is shown at Figure 7.

TRIALS SCHEDULE

The schedule for the month of October is shown at Figure 8. Note that the trial times for each battalion task force is broken into 6-hour blocks. Prior to each major event (movement to contact, night defense, etc), a 6-hour period is allotted to insure that the vehicles and their instrumentation are operational so that full data capture can be assured. As indicated earlier, upon completion of the first four trials on 30 Oct 77, the instrumentation will be removed from the vehicles of the first four battalions and placed on the second set of four. In addition, time is allotted for field training after the instrumentation is installed and before the trials begin. Past experience has indicated that units using the instrumentation are trained to use the terrain much better and, in general, conduct better tactical exercises as a result of the instrumentation.

MANEUVER BATTALION TEST

- TESTS BOTH H-SERIES (BASELINE) AND T-SERIES BNS
- TOTAL OF 8 TRIALS (USING 8 BNS)
  - 4 TRIALS BASELINE (2 BNS EACH OF ARMOR & MECH)
  - 4 TRIALS RESTRUCTURED (2 BNS EACH OF ARMOR & MECH)
- SCENARIO EVENTS, ARTEP BASED
  - MOVEMENT TO CONTACT
  - ACTIVE DEFENSE
  - TACTICAL ROAD MARCH, ASSEMBLY AREA
  - DELIBERATE ATTACK
- ALL BNS PARTICIPATE AS PLAYER & AGGRESSOR
- USES ROUND ROBIN SCHEME
- INSTRUMENTED USING TAFIS (MAIN GUN & TOW)
- DATA TO BE COLLECTED
  - AS SPECIFIED BY CAC FOR WARGAMES & SIMULATIONS
  - TO ANSWER REFINED TEST ISSUES

Figure 4

BN TEST SCHEME

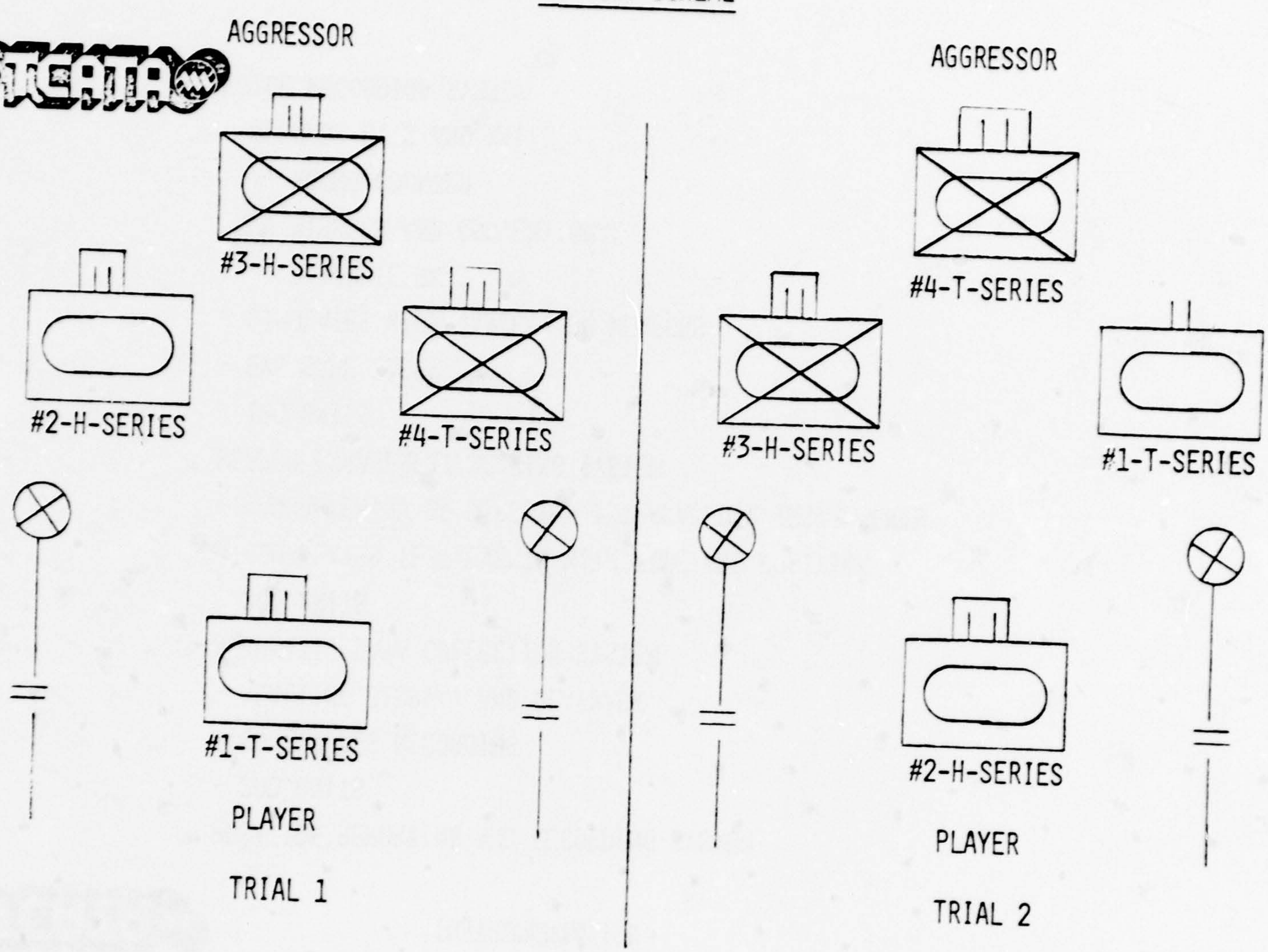


Figure 5

TCATA

INSTRUMENTATION

* POSITION REPORTING AND RECORDING SYSTEM
  - 200 UNITS
  - CONTINUOUS RECORDING
  - REALTIME DISPLAY AND PLAYBACK
* AUTOMATIC DATA COLLECTION SYSTEM
  - 200 UNITS
  - COORELATES TEST EVENTS WITH TIME AND POSITION
  - MANUAL ENTRY OR DIRECTLY INTERFACED W/INSTRUMENTS
* WEAPON ENGAGEMENT SCORING SYSTEM
  - 180 UNITS
  - EYE SAFE LASER
  - SIMULATES WIDE VARIETY OF WEAPONS
    - .. DISCRETE PK
    - .. MISSLES AND CONVENTIONAL
    - .. ROUND COUNTER
  - RECORDS HITS AND KILLS
* VOICE RECORDING SYSTEM

Figure 6

TCATA

FORCE COMPOSITION/INSTRUMENTATION REQUIREMENTS - DEFENSE

TEST	AGGRESSOR FORCE T-SERIES	AGGRESSOR FORCE H-SERIES	FRIENDLY TK	FRIENDLY TOW	FRIENDLY TOT	AGGRESSOR TK	AGGRESSOR TOW	AGGRESSOR TOT	A:F RATIO	TOT INST SYSTEMS
H-SERIES TANK TF	1 TK CO(-)	1 TK CO	22	15	37	42	30	72	1.95:1	109
2 TK CO	2 MECH CO	1 TK CO								
1 MECH CO	1 AT CO	3 MECH CO								
1 AT CO		1 SCT PLT								
1 HVY SCT SEC		1 AT PLT(-)								
H-SERIES TANK TF	3 TK CO	2 MECH CO	34	6	40	39	39	78	1.95:1	118
2 TK CO	3 MECH CO	1 TK PLT(+)								
1 MECH CO (W/2 TOW)	2 AT CO 1 HVY SCT SEC	1 AT PLT(-)								
1 SCT PLT										

Figure 7

TCATA

TRIAL SCHEDULE

	SUN	MON	TUE	WED	THU	FRI	SAT
	16	17 NIGHT DEFENSE	18 ROAD MARCH ASSY AREA	19	20	21 NIGHT DEFENSE	22 ROAD MARCH ASSY AREA
0600	INST CHECKOUT	INST CHECKOUT	INST CHECKOUT	STAND DOWN/MAINT	INST CHECKOUT	INST CHECKOUT	INST CHECKOUT
1200	MVMT TO CONTACT	DAY DEFENSE	DELIBERATE ATTACK		MVMT TO CONTACT	DAY DEFENSE	DELIBERATE ATTACK
1800	INST CHECKOUT	INST CHECKOUT			INST CHECKOUT	INST CHECKOUT	
2400							

	SUN	MON	TUE	WED	THU	FRI	SAT
	23	24	25 NIGHT DEFENSE	26 ROAD MARCH ASSY AREA	27	28	29 NIGHT DEFENSE
0600	STAND DOWN/MAINT	INST CHECKOUT	INST CHECKOUT	INST CHECKOUT	STAND DOWN/INST	INST CHECKOUT	INST CHECKOUT
1200		MVMT TO CONTACT	DAY DEFENSE	DELIBERATE ATTACK		MVMT TO CONTACT	DAY DEFENSE
1800		INST CHECKOUT	INST CHECKOUT			INST CHECKOUT	INST CHECKOUT
2400							

Figure 8

Upon completion of the installation and training, the second set of trials will be conducted during the period 2 thru 16 December.

DATA COLLECTION

Examples of the data to be collected for the first test objective is shown at Figures 9 and 10. Similar data will be collected for the remaining objectives. Note that the data is both objective and judgemental in nature. For example, all the data for 1.1 Effectiveness of Fires, with the exception of documentation of fire control, will be gathered through instrumentation and reduced and statistically tested through automatic data processing. On the other hand, documentation of tactics and techniques employed (1.8) will be accomplished by evaluators at battalion, company, and platoon level. Thus, the evaluators, who will view both types of units during the test, are key to the successful comparison of the current and proposed units. There are a total of 96 evaluators, primarily field grade officers, that will be devoted to the task of both collecting data and rendering judgement as to its meaning.

MILESTONES

The milestones for the Battalion Test are shown at Figure 11. It will culminate with a decision by the Chief of Staff after considerable analysis by the Combined Arms Group of the relative effectiveness of the current battalion and those proposed for the Restructured Division. It can be expected that neither organization as currently structured will be indicated, but that one or the other will be modified in order to provide the best possible battalion structure for the US Army. Similarly, it is expected that the remaining elements of the division can be "fine-tuned" as a result of the division test conducted in the Fall of 1978.

DIVISION TEST

Planning for the Division Test is just getting underway. The scope of the test is shown at Figure 12. Note that this test is not comparative in nature, but rather will provide data on the effectiveness of the Restructured Division which can be compared in models and simulations with existing data on the current division. Particular attention will be paid to the command and control problems of the division and brigades, the Combat Service Support (with emphasis on maintenance, supply, and medical support) and in general, the effectiveness of the support interface between the division and the units of the echelons above division.

SUBLEVEL	MEASURES/REDUCED DATA REQUIREMENTS
1.1 Effectiveness of fires (Fire Distribution and Fire Control).	1.1.1 Kill rates. 1.1.2 Hit rates. 1.1.3 Percent of multiple hits. 1.1.4 Percent of threat loss attributed to each friendly system. 1.1.5 Rate of round expenditure. 1.1.6 Mean engagement ranges. 1.1.7 Fire control documentation. 1.1.8 Loss exchange ratios.
1.2 Weapons positioning.	1.2.1 Weapons firing position documentation. 1.2.2 Mutual support between weapons and units documentation.
1.4 Unit positioning.	1.4.1 Relocate times. 1.4.2 Clear position times. 1.4.3 Occupy position times. 1.4.4 Percent of friendly force that could engage in combat. 1.4.5 Percent of friendly force engaged in combat.
1.5 Tactics and techniques employed.	1.5.1 Documentation of commander's concept. 1.5.2 Documentation of how units operated and accomplished missions. 1.5.3 Documentation of tactics/techniques that improved/degraded unit's effectiveness. 1.5.4 Documentation of deviations in DRS doctrine.

Figure 9

SUBLEVEL	MEASURES/REDUCED DATA REQUIREMENTS
1.6 Observations of key command/staff/ evaluator personnel.	1.6.1 Problems noted. 1.6.2 Solutions to problems. 1.6.3 Recommendations made.
1.7 Comparison of two variations of scouts in T-series tank battalions and comparison between organic H- and T-series scout units.	1.7.1 Documentation of how traditional scout missions were performed with no organic scouts. 1.7.2 Documentation of reduction in combat power when organic units perform scout mission. 1.7.3 Documentation of how missions given to organic section/platoon were accomplished. 1.7.4 Documentation of additional personnel and equipment required to accomplish missions. 1.7.5 Results of prior scout evaluations. 1.7.6 Key personnel observations concerning problems solutions, and recommendations.
1.8 Effect of platoon leader motorbikes (T-series only).	1.8.2 Documentation of who used motorbikes. 1.8.3 Documentation tasks performed while using motorbikes. 1.8.4 Assessment of survivability of platoon leader with motorbikes mounted on tanks. 1.8.5 Opinions of commanders as to any increase in platoon capability from using motorbikes. 1.8.6 Key personnel observations concerning problems solutions and recommendations.

Figure 10

TCATA

BATTALION TEST - FM 382

TEST MILESTONES

EVENT	DATE
COORDINATE DTP	31 AUG 77
START INSTRUMENTATION	12 SEP 77
DETAILED IPR	14 SEP 77
START PRETEST ACTIVITIES	2 OCT 77
START TEST	16 OCT 77
END TEST	16 DEC 77
COORDINATE TEST REPORT	6 FEB 78
REPORT IPR	20 FEB 78
PUBLISH REPORT	20 MAR 78
CAC IER TO TRADOC	
TRADOC IER TO OTEA	
CSA DECISION	JUL 78

Figure 11

TCATA

DIVISION TEST

* 2 - 4 WEEKS (SEPTEMBER 1978)
* 3 BRIGADES, 9 BATTALIONS IN MANEUVER
* EVENTS INCLUDE
  -- SCREEN
  -- ACTIVE DEFENSE
  -- ATTACK
* DIVISION/CORPS SUPPORT
* OPFOR 4 BATTALIONS FROM 2D AD
* EMPHASIS ON COMMAND AND CONTROL, COMBAT SUPPORT, COMBAT SERVICE SUPPORT AND INTERFACE WITH ECHELONS ABOVE DIVISION
* INSTRUMENTATION
  -- LOCATION DATA
  -- EVENT DATA
  -- LIMITED WEAPONS ENGAGEMENT DATA

Figure 12

TITLE: Environment and Radar Operation Simulator

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ABSTRACT: The Environment and Radar Operation Simulator (EROS) is a hybrid system combining a general purpose computer, special purpose digital hardware and analog hardware, whose function is to produce synthetic backscatter. The simulator is electrically connected to a subject radar, and the synthetic backscatter constitutes a simulation of the radar's external world. The purpose of EROS is to reduce the cost of environment testing for battlefield surveillance radars by improving the repeatability and controllability of tests and by replacing much of the field testing with laboratory testing. Battlefield clutter is synthesized by an array of digital filters, which provide controllable amplitude distributions, spatial distributions, and spectra. Targets are simulated by combining recorded backscatter with user-defined maneuvers. EROS interacts with the subject radar by sensing its antenna scan angle and by responding in real time with the correct composite backscatter at video frequency.

ENVIRONMENT AND RADAR OPERATION SIMULATOR

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1. Purpose of Program

The Environment and Radar Operation Simulator (EROS) is a hybrid system combining a general purpose computer, special purpose digital hardware, and analog electronics, whose function is to produce synthetic radar backscatter. The equipment has been built by the Engineering Experiment Station at Georgia Tech under contract DAAB07-74-0272, under the direction of the U. S. Army Electronics Command. The synthetic backscatter produced by EROS combines realistically simulated radar-return components from a variety of targets and clutter. This backscatter incorporates amplitude and frequency fluctuations due to variations in radar cross section, Doppler shifts, and other phenomena. The resulting synthetic waveform is available for insertion into the radar at IF, video, and Doppler.

The simulated scenario is specified by the EROS operator and includes the locations and movements of objects producing radar backscatter: troops, vehicles, vegetation, hills, insects, etc. The scenario description also includes radar and reflectivity characteristics: antenna pattern, range dependence, etc.

The EROS system translates scenario information into signal data in a form appropriate for real-time simulation. During real-time simulation, the EROS system combines scenario data, signals from the subject radar, and operator commands into realistic radar backscatter, which is applied to the radar receiver. This form of simulation permits laboratory testing as an alternative to field testing and has a number of potential advantages:

- EROS testing promises to be less expensive than field testing, because of the convenience of the laboratory as a test site.

- The results are controllable to a high degree of scenario detail. Unpredictable influences such as weather changes do not affect EROS tests.

- The tests are repeatable. This has obvious benefits in experimentation and in repair of radar receiver components.

Signal insertion at frequencies other than RF permits simulated field testing of specific receiver components (e.g., embodying unproven clutter reduction techniques) without having to incorporate this component in a complete radar.

In principle, it is highly desirable for EROS to be applicable to all existing troop surveillance radars and to embody sufficient flexibility to accommodate as yet unspecified radar designs. This is a long-range goal and not a specific objective of the current program. A particular subject radar, the AN/PPS-15, has been chosen to prove feasibility of the EROS concept and design, and EROS has been built to address this radar. However, the design incorporates flexibility that will permit easy adaptation of the first EROS system to other radars.

2. EROS Description

The scenario to be simulated (see Figure 1) is an annular shaped region, which represents the portion of the battlefield visible to the radar. The region is subdivided into concentric rings (at constant range from the subject radar) and radial columns (at constant azimuth with reference to the subject radar). The simulated antenna beam consists of a contiguous subset of m of these azimuth columns. The center of the beam is determined by sampling a voltage from the subject radar, which represents its antenna angle.

The intersection of range rings and azimuth columns defines a subdivision of the scenario into four-sided cells, which will hereafter be called "simulation cells." The concept of the simulation cell is useful in providing a reference for the EROS operator in defining the scenario. Moreover, much of the internal communication between EROS components is expressed in terms of simulation cells.

The EROS hardware consists of a digital computer, special purpose digital hardware, and analog hardware. The flow of data between these components is illustrated in Figure 2. The computer contains a cathode ray tube graphic display unit and approximately 40 million bits of online disk storage. These facilities are used to assist the EROS operator in defining the scenario and to participate in the real-time simulation by supplying control information to the digital hardware. The digital hardware, in turn, generates synthetic clutter backscatter, applies antenna pattern weighting, and combines clutter signals with target signals. The combined data are sent to the analog hardware. The analog hardware applies range-dependent weighting (e.g., R^{-4} power attenuation) and generates a video frequency signal incorporating the subject radar's transmitter modulations.

The target and clutter signals reflect the Doppler and radar cross section fluctuations of the simulated backscatter. In the computer and digital hardware these are expressed in terms of sampled waveforms. Each sample is a complex quantity represented by the two quadrature components of the waveform.

Target signals in EROS are recorded on the computer disk during scenario definition. Additional target data (specified via the computer's

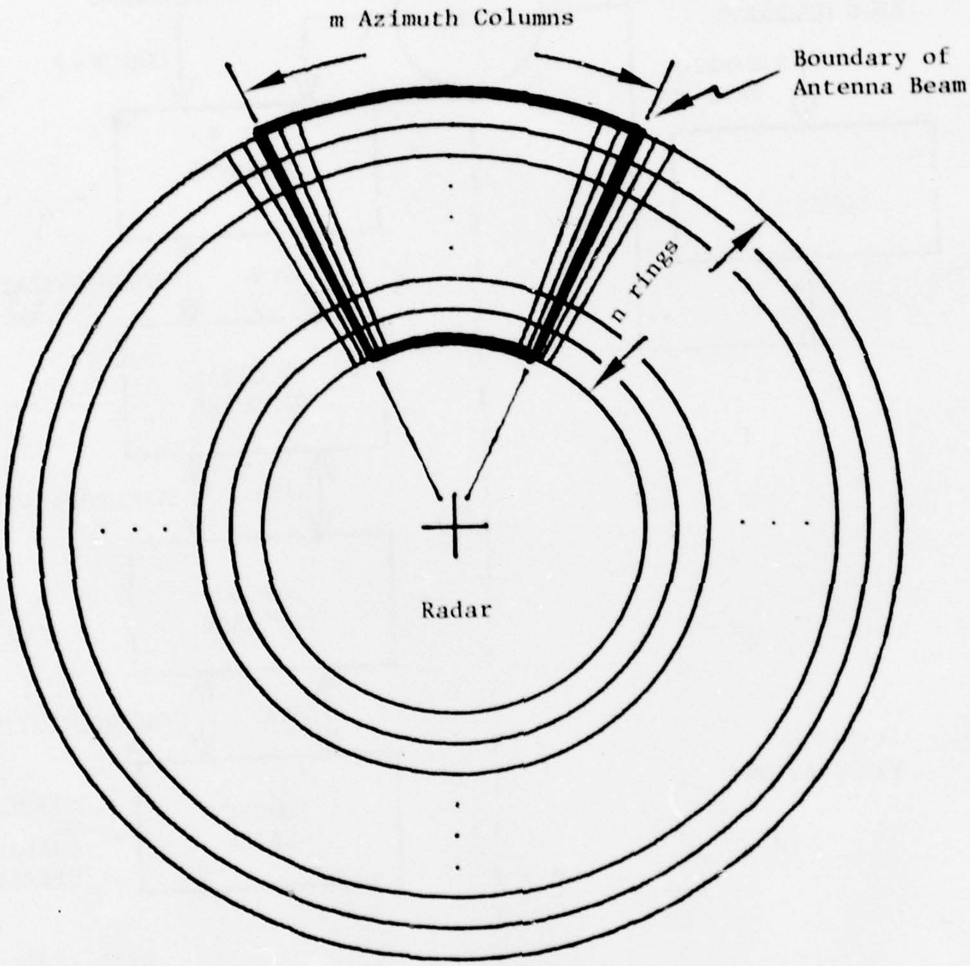

Figure 1. Simulated Coverage Area.

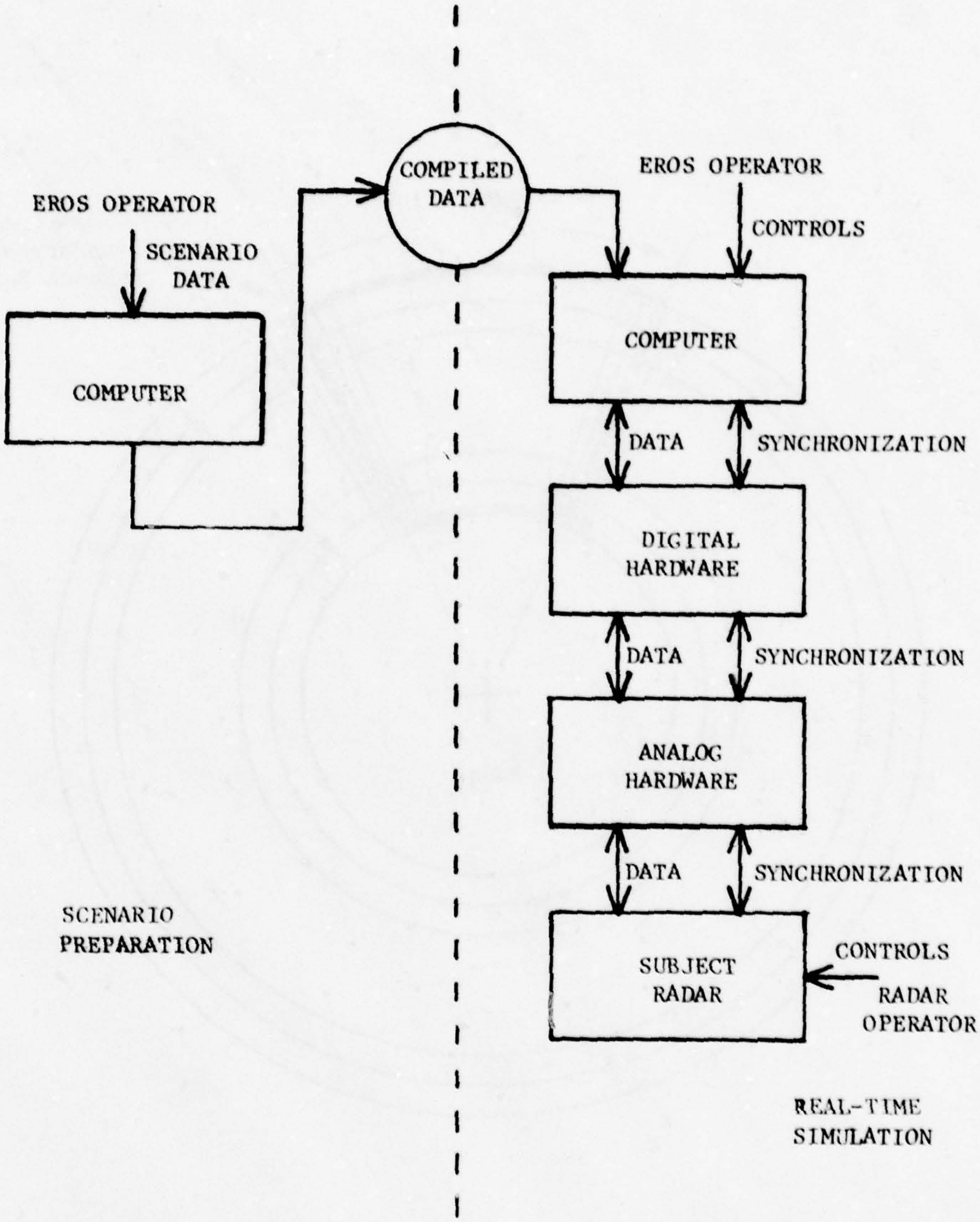

Figure 2. EROS Data and Control Flow.

graphic display unit) consists of target-movement definition and a schedule of events. This information is compiled onto a disk file and is subsequently retrieved for transmission to the digital hardware during real-time simulation. To ensure realism, the target signal strength is apportioned between two adjacent range rings. More precisely, assume that the target's signal strength is s and that the target is between the center of range ring r and the center of range ring r + 1. Let d_0 and d_1 denote the respective distances between the target and the centers of range rings r and r + 1. Then the backscatter from the target is represented as

$$\frac{d_1 s}{d_0 + d_1} \text{ from range ring r and } \frac{d_0 s}{d_0 + d_1} \text{ from range}$$

ring r + 1. The reason for doing this is to avoid an abrupt discontinuity (in range-gated radar reception) as the target crosses the boundary between range rings. A similar problem in azimuth boundaries is avoided by utilizing very high resolution in the representation of the antenna pattern.

Clutter is synthesized in the digital hardware by applying pseudo-random sequences (digital noise) to digital filters. The output from the filters have spectra and amplitude distributions that are controllable as functions of the filter parameters. Clutter backscatter is represented as the sum of the radar returns from moving scatterers (e.g., foliage, insects, etc.) and fixed scatterers (e.g., rocks, buildings, etc.). The return from the moving portion of clutter is created by two identical 2-pole filters, which generate the two quadrature components. The return from the fixed portion of clutter is simply a complex constant. The 2-pole filter employs two feedback multipliers α_1 and α_2. The state of the filter is defined by the most recent output w_1 and the previous output w_2. The transition to the next filter state is described by the computation:

$$w' \leftarrow \alpha_1 w_1 + \alpha_2 w_2 + x$$

$$w_2 \leftarrow w_1$$

$$w_1 \leftarrow w'$$

where w' is the next filter output, and x is the pseudo-random input.

The computations are performed by two identical units of hardware for the two quadrature components. The parameters and state information are maintained in read-write memory--the memory holds one set of such data for each simulation cell in the antenna beam. The filter hardware performs computations in an endless loop:

update the state of filter number 1

update the state of filter number

. . . . .

update the state of filter number k (k denotes the number of filters in the beam)

update the state of filter number 1

. . . .

This arrangement avoids maintaining k sets of hardware for the k simulation cells. Moreover, by permitting the digital computer to write into the parameter memory, it provides a means for simulating the clutter response to antenna scanning. As simulation cells drop off the trailing edge of the antenna beam, new cells enter the leading edge. The computer overwrites the parameters of the trailing-edge cells with the parameters of the leading-edge cells.

One loop through the k cells constitutes one Doppler sampling cycle. The clutter hardware produces samples for k cells during the Doppler sampling cycle. These are combined with a small number (at most two) target-signal samples with their respective antenna-pattern weights and range ring numbers that the computer has sent. These data are combined as follows.

- Azimuth weights are applied to the target and clutter samples (the antenna pattern for clutter is sent from the computer during initialization and the digital hardware stores this array in a random-access memory).
- All clutter samples at the same range are added together (azimuth integration).
- The target samples are added to the appropriate clutter sums (based on the specified range-ring number).

The result is a range profile--one value for each range ring.

The range profile is recomputed at the Doppler sampling frequency, which is several times slower than the pulse-repetition frequency (PRF) of the AN/PPS-15 radar. Therefore, the digital hardware stores each range profile in a random-access memory. This same data is retrieved at the PRF; several repetitions of the same data are used before a new range profile is stored.

The range profile is sent to the analog hardware at the PRF. Each transmission is delayed a fixed interval after the radar's pulse trigger; this delay corresponds to the distance between the radar and the closest simulated range. The range samples are sent in ascending range order. The interval between samples corresponds to the width of the simulated range ring. Each range sample is accompanied by the corresponding range-dependent attentuation. For example, the range attenuation might vary proportional to R^{-2} to simulate R^{-4} power loss. After the transmission of the range sample for the most distant ring, the digital hardware waits for the trigger denoting the next radar pulse.

The analog hardware employs 3 D/A converters: 1 for the in-phase signal component, 1 for the quadrature signal component, and 1 for the range weight. The range weight is applied to the two signal components using an analog multiplier. The signals are then fed through an analog integrator in order to simulate the transmitter modulation of the AN/PPS-15 radar. Finally a controllable amount of analog noise is added to account for antenna and receiver-front-end noise, and the result is applied to the video stage of the AN/PPS-15 radar.

3. Simulation Preparation Software

Simulation preparation software consists of programs to assist the operator in describing the scenario. Much of the information is maintained in reference files (called "libraries"), whose contents may have widespread applicability in many scenarios. All input entered by the user is checked for validity, and diagnostics are written when errors are detected. Generous provision is made for the user to append comments to document his simulation data. Optional printouts permit the user to generate reference reports that define the files' contents and that contain the user-written comments.

The records in the clutter spectral library specify the spectral properties of the clutter filters. Each record corresponds to a different spectral behavior, and is identified by a unique integer. Facilities are provided for the EROS user to add or change records in this library.

The complete clutter library consists of records which contain both spectral and radar cross section information. To define a record in this library the user supplies (1) a 2-character code to identify the record, (2) an integer that refers to a record in the clutter spectral library, and (3) radar cross section values for the fixed and moving components of clutter. The clutter library update program retrieves the spectral information inferred by the given spectral-reference integer. Facilities are provided for the EROS user to add, delete, or change records in the library.

The clutter scenario description program assists the user in defining the positional dependence of clutter. The computer's graphic cathode-ray-tube and light pen are made available to the user to expedite his definition of 8192 cells in the clutter description array. The type of clutter in each cell is identified by the two-character code that refers to a record in the complete clutter library. The user may also need to define a clutter weight array, which specifies an amplification or attenuation to be applied to the radar cross section in each cell. The weights can account for partial masking, range dependence of the cell's areas, incidence angle effects, etc. A unique file name is associated with each clutter description array and each clutter weight array. Facilities are provided for the EROS user to revise an array or to define a new array as a modification to a previously defined array. The clutter scenario compilation program combines specified arrays and reference-file information to produce the "compiled clutter scenario file" in an optimal format for real-time simulation.

The target portion of a scenario is built up from recordings and from target path definitions. The recorded information extracted from the A/D converters is stored on disk files. A unique file name is associated with each recording. The computer's cathode ray tube and light pen are available to the user for describing the target paths, which are depicted in the form of a B-scope display. The target compilation program combines one or two target paths and the recordings referenced in these paths. It produces the "compiled target scenario file" in an optimal format for real-time simulation.

Antenna patterns are represented during real-time simulation by a 4096-point table for attenauting target signals and by a 68-point table for attenauting clutter signals. The user specifies the pattern with 13 points spaced at 1-degree intervals from the beam center. The computer translates this specification into an antenna pattern file which holds the two tables.

The range-weight file consists of 197 attenuation factors corresponding to range rings from 60 to 3000 meters at 15-meter intervals. Specified range-weight inputs are converted to fixed-point format for real-time simulation. Only 64 of these weights are used during any given simulation run. The minimum range for the simulation determines which of these 64 weights to use.

4. Real-Time Software

The user initiates a simulation run by entering the name of an "EROS scenario file." EROS scenario files, which are created by the user via the operating system's text editor, contain the names of the component files:

- a compiled clutter scenario file,
- a compiled target scenario file,
- an antenna pattern file,
- a range-weight file.

During simulation initialization various tables and constants are read into the computer and into digital-hardware memories. These include the antenna-pattern and range-weight tables. EROS starts producing simulated backscatter when the radar's antenna reaches a specified azimuth and is proceeding in a specified scan direction. This increases the repeatability of EROS experiments. After simulation has started, the real-time program responds to the antenna's azimuth by copying appropriate clutter and target data from the disk files to the digital hardware.

5. Digital Hardware

The digital hardware performs those functions, where the speed and the number of computations are beyond the real-time capability of the computer. The data inputs to the digital hardware are supplied by the

computer:

- Filter parameters and current azimuth for clutter
- signal samples, range, and azimuth weight for targets.

The clutter processor continuously calculates synthetic clutter backscatter from 544 cells in the currently simulated antenna beam. Each Doppler sampling cycle consists of performing one computation step for each filter, applying the antenna pattern weights, and performing azimuth integration. The azimuth input from the computer is used to determine which antenna-pattern weight applies to a given cell. Azimuth integration consists of adding together the returns from cells at the same range. The result is a sampled range profile of clutter return

$$s_0, s_1 \ldots s_{63}$$

spaced at 15-meter intervals, such that

$$s_0 = s_1$$

$$s_2 = s_3$$

$$\ldots$$

$$s_{62} = s_{63}$$

The values of these 64 samples are recalculated each 240 μsec.

The target processor applies the azimuth weight to the two quadrature components of each target sample and stores the products with the associated range-ring number in a random access memory (RAM). In general, two such sets of data are required for each Doppler sampling cycle, because part of a target sample is allocated to one range ring, and the balance is allocated to an adjacent range ring. The RAM is capable of storing data for 128 Doppler sampling cycles. Status bits are stored in the RAM to denote the end of each Doppler sampling cycle and the end of 128 Doppler sampling cycles. Two such RAM's are used, so that the computer can load one of them while the target processor retrieves previously loaded data from the other one. Each retrieved sample is added to the clutter range profile at the range specified by the retrieved range-ring number.

The video signal is produced by storing each range profile in a RAM and by reading it back at the radar's pulse repetition frequency (PRF). The Doppler sampling frequency is 1/9 the PRF of the AN/PPS-15 radar; therefore, each range profile is read back 9 times. Two RAM's are used for this purpose, so that one of them can be loaded from the target processor while the video signal is read from the other one.

6. Analog Hardware

Analog hardware is needed in any radar signal simulation to convert digital samples into a form suitable for insertion into the radar. More-

over, in EROS the range-weighting and range-integration functions are performed in analog hardware to meet the AN/PPS-15 radar's dynamic-range and video-bandwidth capabilities.

Twelve-bit D/A converters are available with speeds adequate to process real-time video signals. Three such converters are used: (1) to convert sign and magnitude of In-phase (I) data prior to range weighting; (2) to convert sign and magnitude of Quadrature (Q) data prior to range weighting; and (3) to convert magnitude of the range weight values. The analog output of the range weight D/A converter is multiplied by the I signal and by the Q signal in separate analog multipliers.

For video signal simulation, digital signals representing the I and Q content and range weight of successive range rings are latched into the three D/A converters at 100 nanosecond intervals (which corresponds to about 15 meters in round-trip propagation). Outputs of the analog multipliers are integrated in analog integrators, which are reset periodically by pulses coincident with the transmitter modulation. Since signals from all range rings are present for equal time increments, integration with respect to time is equivalent to algebraic addition of the data from successive range rings. The output from the integrators is a faithful representation of the envelope of AN/PPS-15 radar return, because the radar transmits CW with 180° phase reversals at the PRF. The integrators are also quite effective in reducing the bit-switching transients that are inherent in D/A converters. The output of the integrators are fed into variable-gain video amplifiers, which provide calibration and the addition of adjustable simulated receiver noise. Simple band-pass filters are used to limit the video signal bandwidth to that of the radar preamplifier, and to further attenuate bit-switching transients that originate in the D/A converters.

For simulation of range-gated Doppler signals, the EROS operator selects one of the 64 range rings by means of a knob on the analog hardware. Digital signals representing the I content, Q content, and range weight of the selected range ring are latched into the D/A converters at the transmitter modulation rate, and each sample is held for a time equal to the interval between transmitter modulations. The range integrators have been switched out, and the range weighting analog multipliers are connected through low-pass filters to variable-gain Doppler output amplifiers.

The present method of analog range weighting lends itself readily to simulation of other types of radar modulation. In particular, the bipolar video signal of conventional pulse-Doppler radar differs from the AN/PPS-15 video in that the returns from a single range resolution cell contribute to the video signal at any given point in the interpulse interval. This signal could be simulated in EROS simply by switching out the range integrator and by adjusting signal and noise levels appropriately for the parameters of the radar under test. The range-gated Doppler signal for pulse modulation and for the AN/PPS-15 modulation do not differ in form, and only the adjustment of signal and noise levels is required.

TITLE: DELAY FUZE REQUIREMENTS AND EVALUATION OF 20-30mm AMMUNITION

BRIEFER: JOHN J. McCARTHY, US Army Materiel Systems Analysis Activity

SESSION: TESTING & EXPERIMENTATION

ABSTRACT: In February 1974 The Joint Technical Coordinating Group for Munitions Effectiveness was tasked to conduct a Comparison Study of 20-30mm ammunition in the air-to-air role. The target of interest was the Fishbed-J. In order to conduct this study it was necessary to initiate an extensive Vulnerability Test and Assessment Program.

The primary objectives of the vulnerability test program was:

(a) The ability of an HEI projectile to cause an inlet duct rupture and a fuel ingestion kill in the aircraft.

(b) The probability of a sustained external fuel fire given a hit by an HEI projectile in a full fuselage fuel tank on the dorsal tank considering the effects of altitude and air speed.

A special JTCG/ME report has been prepared on this effort. It is entitled Fishbed Aircraft Vulnerability Study 61 JTCG/ME-76-1.

The paper to be presented will concentrate on the test program. Attached is Appendix B from the referenced study which summarizes the key elements of the test program and results relative to the benefits of delay fuzing against aircraft targets. The data are applicable to air defense studies as well as air-to-air gun evaluations.

TIME: 30 Minutes

APPENDIX B

TEST PROGRAM SUMMERIES

SECTION I – FUEL TANK VULNERABILITY

B-1. (U) PHASE I – COMPARISON OF THE LETHAL RADIUS OF 20MM AND 25MM HEI PROJECTILES AGAINST A VARIABLE GEOMETRY FUEL TANK SIMULATION

a. OBJECTIVE

(1) The objective of Phase I is to determine the critical rupture distance for the 20mm and 25mm projectiles with both point- and delay-detonating fuzes. The critical rupture distance or lethal radius for a projectile impacting the *front* skin at a full fuel tank is defined as the maximum radius between the projectile detonation point and the *rear* skin of that fuel tank which results in a failure of the rear skin (Figure B-1). A failure of the rear skin for purposes of this test and evaluation is defined as a projectile-caused 2-inch or longer crack in the rear skin or the loss of 0.5 square inch or more surface area of the rear skin.

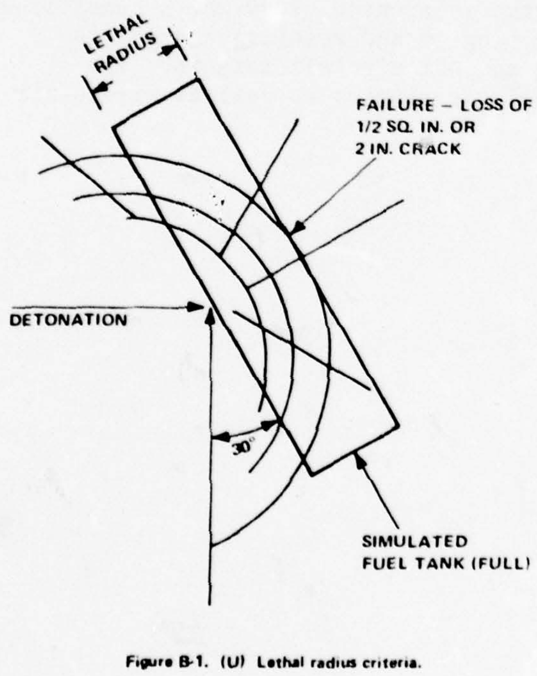

Figure B-1. (U) Lethal radius criteria.

(2) This lethal radius parameter is intended to be utilized as a measure of projectile lethality against a fuselage fuel tank/engine inlet duct configuration. Impacts into the fuselage fuel tank of single-engine, central-inlet-configured aircraft such as the MIG-21 can cause rupture of the fuel tank/inlet duct skin resulting in fuel leakage (ingestion) into the engine inlet duct and subsequently into the aircraft engine itself. When this fuel loss rate into the inlet duct is sufficient, an engine kill and subsequent aircraft loss can result. By modeling critical aircraft and projectile parameters for this test, a determination of the capability of each of the subject projectiles to inflict this type of kill can be determined for various fuel tank thicknesses.

b. TEST SPECIMEN

(1) The Phase I test specimen is a specifically designed Tank Wall Simulator (TWS), designed and fabricated by AFFDL/PTS personnel. It is a multisection tank incorporating four steel sides with replaceable entrance (front) and exit (back) aluminum skins clamped and bolted in place. The tank is configured with a basic 4-inch-thick section with additional sections of various thicknesses bolted to it. The overall size of the TWS is 30 inches high by 60 inches long with thickness varying from 4 to 18 inches. The pressure transducers (five), fill/drain lines, and vent lines are installed in the basic 4-inch section. Other sections are then added to the front to change the TWS thickness when required.

(2) Two impact skin geometries were utilized: single and double wall. The single-wall panel was sized to approximate the single-wall portion of the exterior skin of the MIG-21. The skin was 2024-T3 aluminum, 30 X 60 inches, 0.071 inch thick.

(3) The double-wall panel configuration was similar to that of the single-wall panel with a 12 X 30 X 0.040-inch 2024-T3 aluminum striker plate attached to the fuel tank in front of the 0.071-inch-thick entrance skin.

(4) The exit skin (or back wall), bolted and clamped to the rear of the TWS, was made of 0.100-inch-thick 2024-T3 aluminum. This panel simulates the engine inlet duct skin of the MIG-21.

(5) Fuel tank bladder material was sandwiched between both the simulated skins and the TWS frame. This bladder material was specially fabricated at the Goodyear Tire and Rubber Company, Akron, Ohio, to AFFDL specifications. The thickness of the test bladder material is 0.043 inch.

c. PROJECTILES TESTED

(1) There were basically four different domestic projectiles tested during Phase I. They consisted of the 20mm and 25mm HEI projectile bodies combined with a point-detonating and a delayed fuze. In addition, there were three Soviet projectiles tested as a basis for comparing the effects from the delayed fuze versus the superquick fuze.

(2) For this testing, a *superquick* fuze was defined as one which detonates the round immediately upon impact so that the detonation occurred in free air outside the fuel tank. This type of detonation is always characterized by fragment scratches on the outside of the tank wall. The *delayed* fuze was defined as one which detonates the round a sufficient time after impact to allow the projectile to penetrate the impact skin completely before detonating. All delayed projectiles were estimated to function just inside the external skin.

d. TEST SETUP

(1) The test specimen was installed in the Ballistic Impact Test Facility (BITF), Range No. 2. The TWS was clamped to a stainless steel framework with a catch tank placed beneath the TWS to collect the fuel lost during the tests.

(2) The fuel utilized for the tests was Phillips 220. This fluid has a specific gravity of 0.803 and a flashpoint of 220 degrees Fahrenheit. By using this fluid, blast and hydraulic ram damage is similar to that expected from tankage utilizing actual fuel with a much reduced fire hazard. This fluid was ignited during some tests, but the damage was small and the fire was easily extinguished.

(3) The TWS, when filled with fluid for testing, was pressurized to 1.15 psig. This pressure is representative of differential pressure between typical fuel tankage and static pressure existing in an engine inlet duct during flight.

(4) The gun and tank were oriented to produce an impact with a 60 degree obliquity. The standoff distance was approximately 40 feet.

e. TEST CONDITIONS SUMMARY

External Mach	Static
Fuel Tank Pressure (psig)	1.15
Fuel Amount (gal)	31 to 140
Altitude (ft)	950
Fuel Type	Phillips 220
Impact Skin Thickness (in.)	
Single	0.071
Double	0.040/0.071
Duct Skin Thickness (in.)	0.100
Alloy (aluminum)	2024-T3
Fuel Specific Gravity	0.803
Fuel Flashpoint (°F)	220

f. CONCLUSIONS. Lethal radius is the maximum radius between the projectile detonation point and the rear wall of the TWS resulting in a failure of that wall. Because of the difficulty in determining the exact detonation point of some projectiles and that detonation point's dependency on specimen configuration, it is necessary to bracket the lethal radius (including a range of detonation distances) based on best estimates of projectile detonation points. Critical Tank Thickness (CTT) for each projectile/fuel configuration (the maximum TWS thickness resulting in rear-wall failure) will also be given.

(1) 20mm Superquick/Single Skin. The lethal radius and critical tank thickness are both less than 4 inches. inches.

(2) 20mm Superquick/Double Skin. The lethal radius is less than 5.35 inches and the critical tank thickness is less than 4 inches.

(3) 20mm Delay/Single Skin.[1] The lethal radius is between 4 and 6 inches and the critical tank thickness is equal to 8 inches.

(4) 20mm Delay/Double Skin. The lethal radius is between 4 and 6 inches and the critical tank thickness is equal to 8 inches.

(5) 25mm Superquick/Single Skin. The lethal radius and the critical tank thickness are both 6 inches.

(6) 25mm Superquick/Double Skin. The lethal radius is less than 5.35 inches and the critical tank thickness is less than 4 inches.

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[1] *Includes 20mm Improved.*

(7) 25mm Delay/Single Skin.[1] The lethal radius is greater than 14 to 16 inches and the critical tank thickness is greater than 18 inches.

(8) 25mm Delay/Double Skin. The lethal radius is greater than 14 to 16 inches and the critical tank thickness is greater than 18 inches.

B-2. (U) PHASE II – COMPARISON OF 20MM, 20MM IMPROVED, AND 25MM HEI PROJECTILE EFFECTIVENESS AGAINST A MODIFIED A-7 REPLICA FUSELAGE

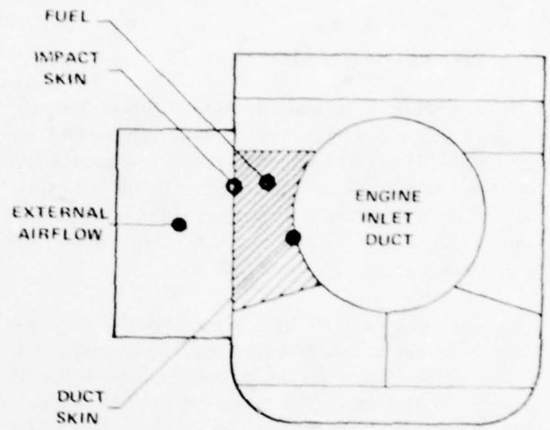
a. OBJECTIVE

(1) The objective of Phase II is to compare the effectiveness of the 20mm (M56), the 20mm Improved, and the 25mm rounds against a simulated single-engine, fighter-type, aircraft target by means of gunfire testing in a realistic environment. The comparison of these three projectiles will be based on several parameters to be extracted from the test results. These parameters include probability of fire versus airflow velocity, hydraulic ram pressures, structural damage, and inlet/engine fuel ingestion. In these tests, the effects of airflow velocity on the probability of fire were investigated by attempting to define the maximum airflow velocity at which a sustained fire can be initiated by impacts of the test projectiles. The fuel ingestion rates and structural damage to the inlet duct skin were also monitored, and these data serve as an additional basis for comparison.

(2) An impact into fuselage fuel tankage by an HE projectile can result in a sustained fuel fire in and around the impact wound which, in turn, can result in an aircraft loss. In addition, an impact into fuselage fuel tankage of single-engine, central-inlet-duct-configured aircraft can cause rupture of the fuel tank/inlet duct skin resulting in fuel leakage into the engine. When this fuel ingestion rate is sufficient, an engine kill and subsequent aircraft loss can result. By modeling critical aircraft and projectile parameters for these tests, a determination of the capability of each of the subject projectiles to inflict these types of kill can be assessed.

b. TEST SPECIMEN

(1) The Phase II test specimen is a modified A-7 replica fuselage. It is a stainless steel skeleton that allows realistic panels to be fastened in place as tank walls. For the Phase II tests, the right-hand forward tank was used (Figure B-2).



IMPACT AND DUCT SKINS TYPICAL MIG-21 MATERIAL AND THICKNESS

Figure B-2. (U) Modified A-7 test specimen.

(2) The impact skin included two different configurations: a single and a double wall. The single-wall panel was made of 2024-T3 aluminum, 30 X 60 inches, 0.071 inch thick. The double-wall panel was of the same overall dimensions as the single-wall panel but was fabricated utilizing a 0.025-inch-thick inner skin, a 0.040-inch-thick outer skin, and a combination of angle and Z-section stiffeners to produce an overall thickness of 1.35 inches (Table B-1). All materials were 2024-T3 aluminum. The duct skin was a single sheet of 2024-T3 aluminum, 0.100 inch thick, rolled to the contour of the duct with no intermediate stiffeners. Fuel tank bladder material was sandwiched between the simulated skins (both the impact and the duct skins) and the stainless steel framework. This type of arrangement simulated the presence of a fuel tank bladder and also served as a gasket to seal the panels. This bladder material was specially fabricated at Goodyear Tire and Rubber Company, Akron, Ohio, to AFFDL specifications. The thickness of the test bladder material is 0.043 inch.

(3) The tank cross section is depicted in Figure B-2 and holds approximately 75 gallons of fuel.

[1] *Includes 25mm Bushmaster with 714 fuze.*

c. **PROJECTILES TESTED.** Four projectiles were tested during Phase II:

- 20mm HEI (M56)
- 20mm HEI (M56) with Delay Fuze
- 20mm HEI Improved
- 25mm HEI Delay Fuze

d. **TEST CONDITIONS SUMMARY**

External Mach	0.3 – 0.73
Fuel Tank Pressure (psig)[1]	3.0 & 1.15
Inlet Duct Static Pressure (psig)[1]	1.85 & 0.0
Fuel Tank/Inlet Duct Differential Pressure (psid)	1.15
Fuel Amount (gal)	75
Fuel Type	Blend of JP-4 & JP-5
Fuel Flashpoint (°F)	102
Fuel Temperature (°F)	60
Altitude (ft)	950
Impact Skin Thickness (in.)	
Single	0.071
Double	0.040/0.025
Duct Skin Thickness (in.)	0.100
Alloy (aluminum)	2024-T3
Impact Obliquity (deg)	60

[1] *A delta pressure ($P_{tank} - P_{duct}$) was maintained at 1.15 psig.*

e. **RESULTS.** A total of 37 tests were performed with the modified A-7 replica fuselage in the AFFDL/Aircraft Survivability Research Facility. The tests are divided into eight different series dependent on test specimen configuration/test procedure/test projectile. Two different types of kill mechanisms were investigated in the Phase II testing. First, and of primary importance, is the kill due to a sustained fire in the fuel tank. Second is an engine failure due to the ingestion of raw fuel from a ruptured inlet duct/fuel tank wall. The results are presented in Tables B-1 and B-2.

Table B-1. (U) Results of Phase II Test – Inlet Duct Failure

Code	Single Wall[1]	Double Wall[1]
Code 1 (20mm)	0 Failures/6 Tests (10 Not Applicable)	0 Failures/2 Tests
Code 2, 5 (20mmD, 20mm Imp)	8 Failures/8 Tests	0 Failures/2 Tests
Code 4 (25mmD)	6 Failures/6 Tests	2 Failures/2 Tests

[1] *Failure = 10 GPM or greater fuel ingestion.*

Table B-2. (U) Results of Phase II Test – Sustained Fire

Code[1]	Double-Skin Short Fuselage		Single-Skin Short Fuselage		Single-Skin Long Fuselage[2]	
	Velocity		Velocity		Velocity	
	200	500	350	475	350	475
Code 1 (20mm)	1/1	0/1		2/3	0/5	0/5
Code 2 (20mmD)				0/2		
Code 5 (20mm Imp)	1/1	0/1	2/2	0/2		
Code 4 (25mmD)	1/1	0/1		1/3		

[1] *Values are given for number of fires/number of tests.*

[2] *Long fuselage includes and 8-foot aft fairing, larger airflow nozzle, top and bottom flow fences.*

B-3. (U) PHASE III – EFFECTIVENESS OF HEI PROJECTILES AGAINST A FISHBED J REPLICA FUSELAGE FUEL TANK

a. OBJECTIVE. The objective of Phase III is to compare the effectiveness of the 20mm (M56), the 20mm Improved, and the 25mm HEI projectiles against a replica foreign target by means of gunfire testing in a realistic environment. The specimen used in this phase was a replica Fishbed J type aircraft fuselage fuel tank. The comparison of the three test projectiles was based on several parameters to be extracted from the test results. These parameters include probability of fire, hydraulic ram pressure, and structural damage. Of these, the major parameter is the probability of sustained fuel fire. In these tests, the effects of airflow velocity and altitude on the probability of fire were investigated by attempting to define the combination of altitude and airspeed conditions at which a sustained fire can be initiated by selected impacts of the test projectiles. The hydraulic ram pressures and structural damage to the inlet duct skin were used as an additional basis for comparison.

b. TEST DESCRIPTION.

(1) Target. The target was a replica Fishbed J fuselage section containing a non-selfsealing, bladder-type fuel cell of approximately 200 gallons capacity. The fuselage section accurately simulated the fuel cell configuration and the surrounding fuselage structure. The target construction allowed for replacement of the damaged portions of the target without requiring extensive repair or replacement of the complete fuselage section.

(2) Fuel. The fuel cell was filled with a JP-5/JP-4 fuel mixture for each test shot and pressurized to 3.5 psid during the test. The fuel within the fuel cell was conditioned to the temperature representative of a typical mission profile.

(3) Airflow. For test position A, both external and inlet duct flow were established. The external flow temperature represented the total temperature for the specified altitude and Mach number. The flow in the inlet duct represented the conditions at the engine compressor inlet for the engine operating at military power settings. The section of the fuselage skin wetted by the airflow was large enough to completely cover the damaged portion of the target.

(4) Obliquity Angle. All the projectiles were fired from a position such that the angle between the fuselage section's longitudinal centerline and the line-of-flight of the projectile is not greater than 30 degrees. The stand-off distance from the end of the gun muzzle to the projectile impact point was 8 feet or greater. Projectile impact locations are shown in Figure B-3. Figure B-4 illustrates the replica target installation.

c. PROJECTILES TESTED. The following projectiles were tested during Phase III:

Type	Fuzing	Velocity
20mm (M56)	Superquick	2800 ft/sec
20mm Imp	Delay	3200 ft/sec
25mm	Delay	3650 ft/sec

d. TEST CONDITIONS SUMMARY

Fuel Loading	
Main Fuel Tank	Full, 30% ullage, 60% ullage
Dorsal Tank	Vapor Filled
Fuel Temperature (°F)	60
Fuel Type	Simulated Soviet Fuel
Fuel Pressure (psi)	3.5
Airflow Velocity (kts)	350, 475
Altitude (ft)	5,000 to 35,000
Inlet Duct Flow (Mach)	0.52
Impact Obliquity (deg)	60

e. RESULTS. The sustained fire results for the 20 shots are summarized in Tables B-3 and B-4.

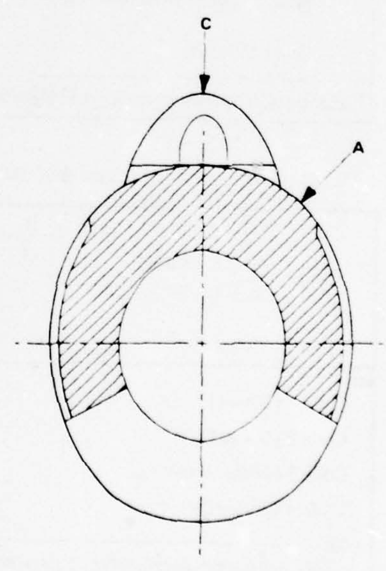


Figure B-3. (U) Projectile impact locations.

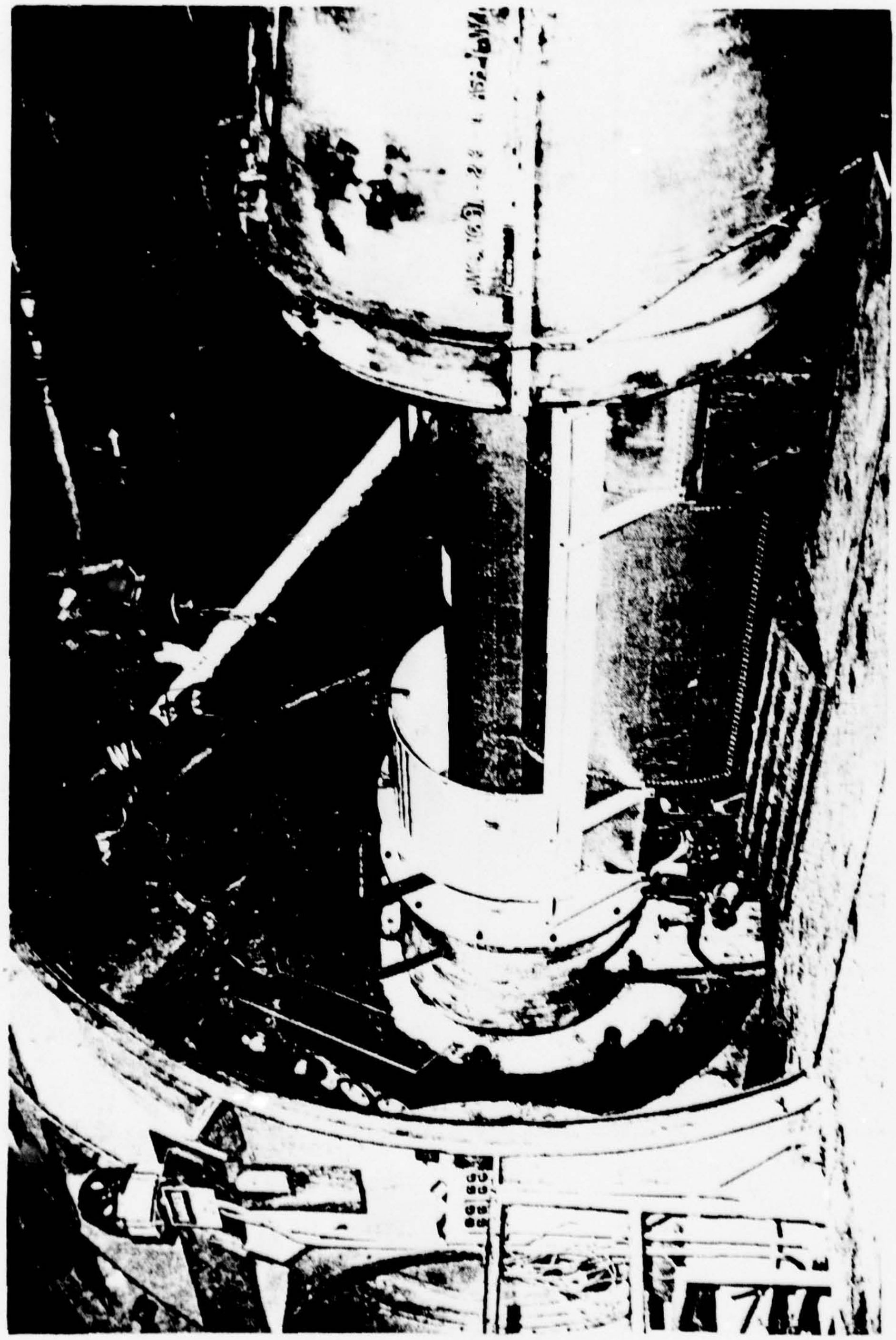


Figure B-4. (U) Replica target installation.

Table B-3. (U) Phase III Fuel Fire Data – 20mm M56

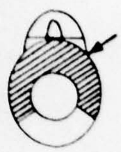
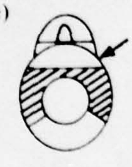
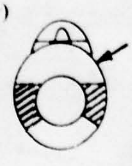
Tank	Airspeed (kts)	Altitude (ft)	Number of Tests	Number of Fires
Main Tank (full) 	475	15,000	3	0
	350	15,000	3	0
	350	5,000	1	0
Dorsal Tank (empty) 	475	15,000	2	2
	475	20,000	2	0
	475	25,000	2	0

Table B-4. (U) Phase III Fuel Fire Data

Tank	Airspeed (kts)	Altitude (ft)	Number of Tests/ Projectile	Number of Fires
Main Tank (30% Ullage) 	475	15,000	2/20mm M56	0
Main Tank (60% Ullage) 	475	15,000	2/20mm M56	0
	475	15,000	1/20mm Imp	Unknown
	475	15,000	1/25mm	Unknown

TITLE: Analysis of Laser Designation Errors

AUTHORS: Julian A. Chernick and John F. Sheldon
US Army Materiel Systems Analysis Activity

ABSTRACT: Data from the 1976 MIRADCOM Laser Designator Test was analyzed to determine statistical parameters that allow the designation errors to be represented by analytic formulas. The various test runs were grouped by common subsets of the test data to allow the sensitivity of the errors to the independent parameters of the test to be quantified. Means and standard deviation of the bias errors for each data subset and the standard deviation of the random errors about the bias errors were computed assuming the errors were independent in time--a valid assumption for sampling times greater than about 1/2 second. For sampling times shorter than this, an autoregression model was exercised to determine the model order and parameters required to describe the process for each common data subset.

TITLE: Analysis of Laser Designation Errors*

AUTHORS: Julian A. Chernick and John F. Sheldon
US Army Materiel Systems Analysis Activity

1. BACKGROUND

During the period 12 November through 2 December 1976, the US Army Missile Research and Development Command (MIRADCOM) by direction of the Project Manager for Precision Laser Designators, with assistance from various other interested Army organizations, conducted a test of designation accuracy (sum of human tracking and atmospheric scintillation effects) of the three laser designator systems currently under various stages of development by the services. They are the Ground Laser Locator Designator (GLLD), the Modular Universal Laser Equipment (MULE) and the Laser Target Designator (LTD). Both the GLLD and MULE are tripod-mounted and are combined designators/rangefinders, while the LTD is a smaller hand-held designator-only unit. These lasers can provide target designation for terminally guided weapons such as COPPERHEAD and HELLFIRE. Only first generation experimental units were available.

2. BRIEF DESCRIPTION OF TEST AND DATA COLLECTED

Twelve "user personnel" were selected from Fort Campbell, KY to operate the designators under a variety of representative test conditions presented from a partially balanced test matrix (described more fully in Reference 2). A total of 766 test runs were made (234 with GLLD; 284 with MULE, and 248 with LTD). The targets were rectangular panel boards with silhouettes of the front and side view of the T-62 tank. The boards were larger than the silhouettes to allow the measurement of most of the laser pulses that might miss the target in order to obtain a more complete set of data for the estimation of the error statistics. Both a marked and an unmarked target was used for the front view condition. The side view targets were also tested at both stationary and moving conditions (constant crossing speeds of 10 mph and 20 mph) while the front view only involved stationary conditions. Target range took on about 3 or 4 different values depending on the designator being tested. In side experiments the effects of canting the GLLD and MULE by 10 degrees and the operator posture/supporting technique of the LTD were compared. Boresight checks were conducted on a daily basis for the GLLD and MULE.

A variety of measurement equipment was used, so that if one system were to fail on a given test run, results from the backup systems would be used instead. Designation error records were generated automatically from the primary systems and from manual film reading when some of the backup measurement systems were used.

The data for all test runs were compiled on a digital tape with a copy sent to AMSAA for analysis. The data tape consisted of: 1) Header record for each run (run number, measurement system, designator-to-target range, designator type, operator, target view, velocity, visibility range); 2) Horizontal and vertical designation errors (coordinates

*This effort is described more fully in Reference 1.

of the energy centroid of the laser spot on the panel in meters referenced to the center of the turret ring) on a pulse-by-pulse basis.

When pulses were not detected by the measurement system a special code was placed on the data tape. This situation could have been due to the laser operator or designator failing to transmit a pulse, the measurement system failing to detect a pulse on target, or the laser beam wandering off the target panel altogether. The durations of the individual test runs were generally between 17 and 20 seconds.

3. STUDY APPROACH

Two methods of analysis were investigated, with the difference between them depending on whether or not the designation errors were considered to be correlated in time. To put it another way, the errors are time correlated, provided the error series is sampled frequently enough, (i.e. errors from one pulse are correlated with the errors from the previous few pulses) and hence a time correlated model is necessary, while if sampling is not required as frequently, (i.e. every 1/2 second or more) the errors appear to be uncorrelated, and hence the random process assumption is valid. Following the chronology of the study the random process error model results will be described first.

4. RANDOM PROCESS MODEL RESULTS

Preliminary results from a sample of the test runs led some to speculate that the laser designation errors may not be normally distributed. Since most of the weapons effects techniques that have been developed over the years are centered around normal distribution assumptions, the first effort involved establishing a method whereby normal and non-normal runs could be distinguished. It was found that the visual examination of frequency distribution histograms of the designation errors sufficed for this purpose and could be obtained quickly for all test runs by using the computer line printer histogram subroutines. The additional expenses of making goodness-of-fit tests for each run was not considered to be warranted for this purpose. However, had the goal been to determine whether a different distribution (say the Weibull) fit the data better than the normal, the use of goodness-of-fit tests may have been appropriate.

It was found that the percentages of runs involving non-normal errors were insufficient to require altering the basic assumptions of normality, only about 8% of the GLLD, 9% of the MULE, and 16% of the LTD runs. The non-normal runs were investigated in greater detail by examining time history plots of the horizontal and vertical errors, and scatter plots of the horizontal versus vertical error coordinates on a pulse-by-pulse basis. Three major categories (with subcategories) were found to account for virtually all the non-normal runs. Some correlations of these categories with the test variables were noted. Improvements in tracking seemed to be correlated with conditions of stationary unmarked targets and close range. The appearance of large errors that were quickly compensated for appear to be correlated with moving targets and/or medium to large range. Large error scatter (nearly uniform distributions) in both coordinates was found to

correlate with the combination of moving targets and generally poorer visibility conditions.

Since the indicated correlations suggest reasonable causes of the non-normal data as opposed to equipment malfunctions or operators not following correct procedures it was felt more likely than not that similar percentages of non-normal errors would occur in any future use of laser designators. Therefore the inclusion of the non-normal runs in the data base was judged to be preferable over their exclusion for the purpose of obtaining best estimates of the designation errors, although differences would be minor in either case.

The next step involved determining the sensitivity of the error statistics to the independent variables of the test. To accomplish this a reduced set of data for each test run was established, consisting of run identification data, levels of the test variables, and the error means and standard deviations. A program was written to rearrange the reduced data into various common subsets of the independent variables of the test, and calculate statistical parameters of the errors for the common subsets. Care had to be exercised to do this consistently with the test design plan in order to minimize the confounding effects of uneven distributions of secondary test variables within each data subset. For instance, when attempting to isolate the effect of horizontal angular velocity on the errors, the data had to be further separated by target view since the front view only involved stationary conditions while the side views did not.

It was found that the simple situation of a single normal distribution of errors with parameters being functions of the test variables failed to adequately describe the test results, but instead, distributions of both bias and random errors were required. The situation is analogous to the two distributions involved in weapons delivery problems, the mean points of impact (bias) errors and the precision (random) errors. It also was necessary to compute somewhat unusual sounding statistics such as the standard deviation of the run means and the means of the run standard deviations. To avoid the possible confusion these statistics-of-statistics could create, they have been given the following names:

bias error = mean of a run

random error = standard deviation of a run

mean bias = average of the run means

sigma bias = standard deviation of the run means

sigma random = average of the run standard deviations.

The statistic-of-statistic missing from the above list is the standard deviation of the run standard deviations. While useful for calculating confidence bounds about the random error curves, this statistic was found to be typically 1/2 to 1/3 of the average of the run standard deviations. For this reason it was felt justifiable to allow the random errors to be characterized by their average within each subset of common runs. Hence, there resulted two distributions and three parameters for each subset of runs: the distribution of bias errors

with the parameters mean bias and sigma bias, and a distribution of random errors about the bias errors with the parameter, sigma random.

Within the limits of the test conditions, the sensitivity of the error statistics to the independent variables followed the approximate order:

a. Horizontal angular velocity

b. Target view

c. Designator support/operator posture for the LTD

d. Operator

e. Designator-to-target range

f. Cant angle (for the GLLD, MULE)

g. Visibility range

Typical trends are shown in Figure 1. Error magnitudes had to be deleted in order to keep the results unclassified. Results are not inconsistent with those from Reference 3 under roughly the same conditions. Before trying to interpret these type of curves it should be realized that the confidence bounds are tighter on the random error curves than on either of the bias error curves, mainly because the number of error samples per run was much greater than the typical number of runs in the common data subsets. Also, no particular significance should be drawn regarding departures from monotonic relations in the sample curves, because confounding effects of other test variables in the subsets of data, the possible effects of uncontrolled variables as usually occur in field tests, and the fact that the repeatability of human performance is rarely exact. A multiple regression approach might have been helpful in smoothing the curves but was beyond the intended scope of the effort.

In any case many observations about the designation errors can still be made with considerable assurance and some of these are discussed below. With regard to the effect of the target velocity it was found that the errors tended to scale better with angular velocity than linear velocity, that the operators tended to lag the moving targets somewhat, and that both the horizontal and vertical random errors increase with target speed as would be expected of a more difficult tracking task. The most significant effect of the target view is the larger (negative) mean horizontal bias error for the unmarked side view target, very likely the result of the influence of the hull's horizontal centerline over the turret ring's centerline in the operator's choice of aimpoint despite the test instructions. (Since only stationary data was used for the target view curves, velocity lag is ruled out.) In attempting to compare the target front view with the side views, more complicated effects arise which may be better understood if one hypothesizes the random errors are more closely related to the difficulty of the tracking task while the bias errors are more closely related to the amount of freedom the operator has in choosing his aimpoint. One notes that the random errors are generally larger for the front view than for either of the side view targets, consistent with the idea that the operator's task is more difficult for the smaller target. Also the horizontal

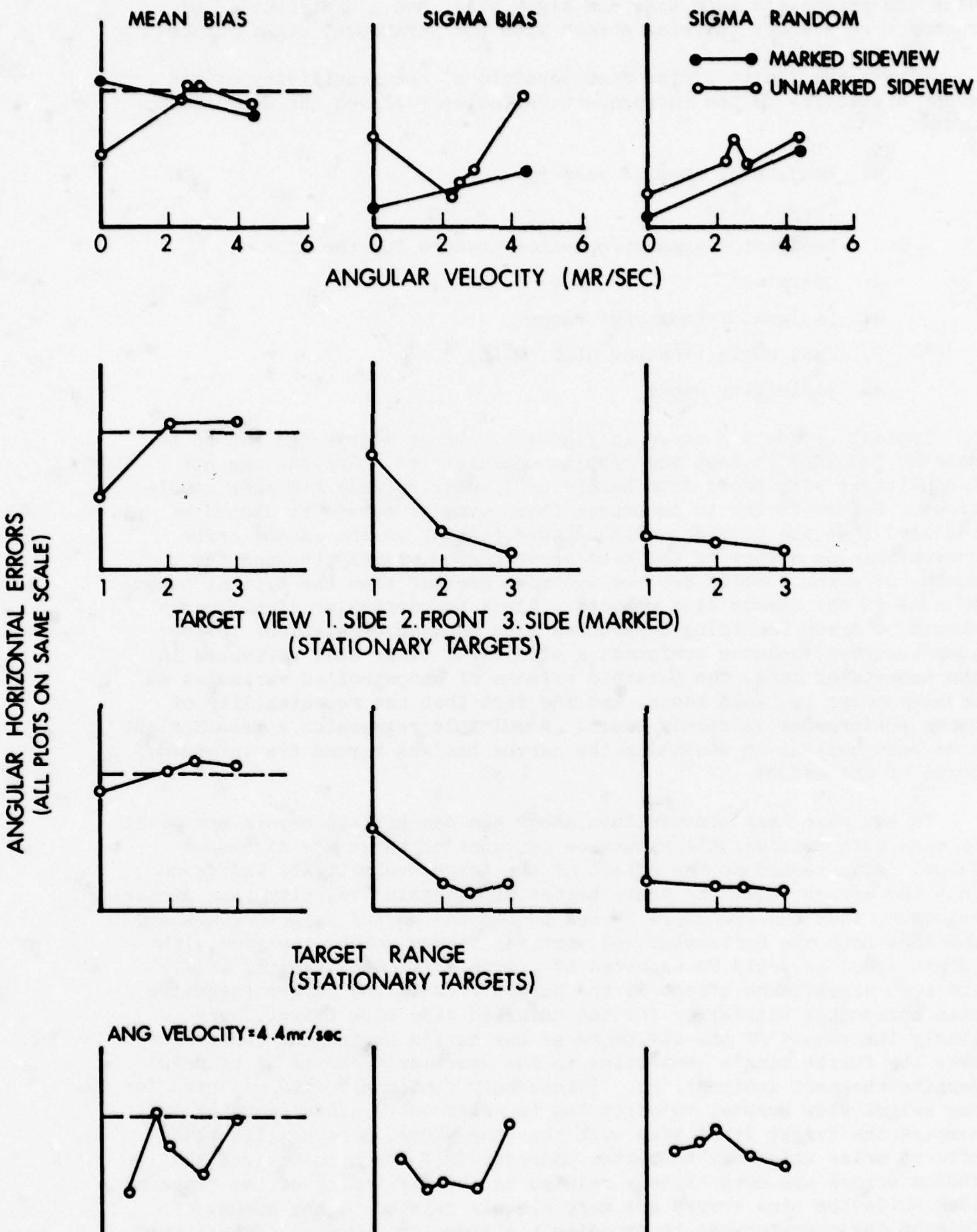


Figure 1. Relative Sensitivity of GLLD Designation Error to Test Variables.

bias errors are smaller for the front view (which was unmarked) than the unmarked side view target in accord with the above hypothesis since the operator had less choice of where to aim in the front view case. The vertical errors do not fit the pattern, possibly because of the effect of a fairly good vertical reference present for all targets (marked or not) in the baseline of the turret.

With regard to the effect of range, two possible effects should be distinguished. The first is the effect of range on the target's apparent velocity which as already mentioned is taken care of best by considering the angular velocity as the independent variable rather than the linear velocity. Secondly, range affects the errors by altering the targets angular size. The main range error effect found was the comparative constancy of the random (angular) errors for stationary targets. Not enough data was available at the higher angular velocities to allow a thorough examination of any range/angular velocity interactions.

The limited amount of poor visibility conditions seemed to verify the poorer designation performance under these conditions particularly for the harder task involving moving targets.

5. TIME CORRELATED MODEL RESULTS

For time intervals not greater than a few interpulse periods a correlation exists between the error at one interval and the error at previous intervals. An examination of the autocorrelation function of the time series helps to quantify the amount of this correlation. For discrete time series the normalized autocorrelation function is defined in terms of a summation of the discrete values by

$$\rho(K) = \frac{\sum_{t=1}^{N-K} (X_t - \overline{X})\,(X_{t+K} - \overline{X})}{\sum_{t=1}^{N} (X_t - \overline{X})^2} \qquad (5.1)$$

where N = total number of time intervals of data

K is the constant time shift between the errors being compared (called the lag).

For most processes the maximum correlation, except for the trivial case when K=0 and hence ρ=1, occurs when K=1 and decays to small amplitude random oscillations by the time K approaches N. In Table 1 we show for each designator the average values for all test runs, of the maximum correlations and number of data lags it took the autocorrelation function to decay below the significant level ($\sim$0.3). This level is approximate since it was chosen by estimating at what lag the behavior of the autocorrelation function of a sampling of test runs changed from a decaying nature to an oscillatory one.

TABLE 1. AUTOCORRELATION FUNCTION PARAMETERS

Designator	Coordinate	Maximum Autocorrelation	Number of Lags Until Decorrelation
GLLD	X	.66	6.8
	Y	.62	6.7
MULE	X	.58	6.4
	Y	.66	7.3
LTD	X	.78	8.8
	Y	.85	8.8

Since the laser guided missiles are programmed to unlock if a number of consecutive pulses are not received and from Table 2 we note the tracking error correlation can persist for 6-9 consecutive pulses, it is conceivable the trajectory could be different depending on which error analysis method is used: either the autoregressive model, or the method that assumes the errors propogate randomly with time. How significant this difference is can only be determined by comparing simulation results using designation errors generated from both analysis methods, a task beyond the scope of this study. However, it is anticipated that the hit probabilities would be lower (although possibly not much lower) if correlated errors are considered since the probability of consecutive pulses missing the target is higher for this case, than when the random process is assumed (and hence when one pulse is off the target the chances are good the next pulse would be back on the target).

In order to provide a representation of the tracking errors valid for short time intervals an autoregression (AR) model described in Reference 4 was utilized. The second-order AR model has the form:

$$E_t = \alpha_1 E(t-\Delta t) + \alpha_2 E(t-2\Delta t) + \beta_2 \eta + \overline{E} \qquad (5.2)$$

where

E_t = error at time t

Δt = interpulse period

α_i = weighting coefficient of the i^{th} previous error (autoregression coefficient)

β_2 = sigma of the residual random noise series (function of model order)

η = normal random number (mean = zero; sigma = 1)

$\overline{E}$ = bias for the runs

TABLE 2. SENSITIVITY OF AUTOREGRESSION PARAMETERS TO THE HORIZONTAL ANGULAR VELOCITY

Designator	Target View*	Angular Velocity (mr/sec)	Horizontal Errors** Mean	Sigma	Alpha 1	Alpha 2	Vertical Errors** Mean	Sigma	Alpha 1	Alpha 2	Sample Size
GLLD	1	1			.400	.162			.369	.130	33
		2.3			.879	-.031			.608	-.049	7
(Non-canted)		2.5			1.131	-.228			.760	-.026	7
		2.9			.969	-.081			.690	.139	11
		4.4			.882	.006			.608	.163	21
	2	0			.648	.025			.706	.010	106
	3	0			.312	.154			.291	.076	31
		4.4			.839	.016			.557	.221	22
MULE	1	0			.239	.185			.389	.279	36
		2.5			.669	.051			.476	-.112	7
(Non-canted)		2.9			.669	.063			.673	.042	8
		3.5			.734	.072			.646	.090	8
		4.4			.907	.006			.698	.132	25
	2	0			.535	.071			.592	.179	88
	3	0			.211	.143			.410	.195	36
		4.4			.854	.012			.610	.133	23
LTD	1	0			.536	.192			.779	.070	35
(Foxhole;		4.4			1.27	-.399			.913	-.046	12
Horizontal)	2	0			.671	.102			.845	.020	85
	3	0			.517	.212			.858	-.002	36
		4.4			1.188	-.350			.846	-.027	12

*Target Views: 1. Unmarked Side; 2. Unmarked Front; 3. Marked Side

**Mean and Sigma Errors are for the residual random noise series; Alpha 1 and Alpha 2 are the first and second autoregression coefficients of the second-order autoregression model.

The procedure used to determine the optimum model order was modified for the data from this test compared with the procedure described in Reference 4. The algorighm first estimates parameters for all model orders between 1 and a user specified maximum value (M_{max} = 10 was chosen). Then the residual noise series variance is scanned to determine which model order minimizes this variance, since when this is done the maximum information (or trends) have been incorporated in the autoregression terms. However, because the residual noise variances were extremely small, and about of the order of the expected measurement system accuracy (sigma $\sim$0.01m) one finds the relative minimum often does not occur until model order 4 or more whereas the difference in the noise variance between model orders 1 and 2 was less than the expected measurement accuracy.

When the criterion of the difference in random noise variance being within the expected measurement accuracy was used it was found that a second order model was adequate to represent designation errors for all three designators. It is worth mentioning that a second order autoregressive model was found to adequately describe GLLD operator tracking errors from a different set of test data (Reference 5).

In Table 2 are shown the average parameters of the second order models for each designator and target view as functions of the horizontal angular velocity. No adjustment for boresight errors was made for the time correlated error analysis study. Only the last 10 seconds of tracking data were used since large errors at this time would be more critical to the missile trajectory. One notes that the first autoregression coefficient (Alpha 1) tends to increase with angular velocity for both the horizontal and vertical directions. For the LTD designator the second autoregression coefficient (Alpha 2) becomes more negative as the target angular velocity increases indicating a tendency to overcompensate tracking corrections particularly for the faster moving targets. The mean and sigma columns of Table 2 refer to the residual random noise series ($\bar{E}$ and $\beta_2\eta$ of formula 5.2).

A comparison check was made on the time series generated from the second order AR models with the parameters estimated from the test data. This involved comparing the means and sigmas of the grouped test conditions from the field test data with those from the AR models. Good agreement was noted in spite of the slightly different durations used in the two sets of data.

An examination of the cross-correlation of the horizontal and vertical tracking errors (either at the same or at different times) showed the effect to be minor. In other words, the horizontal and vertical errors were essentially independent of each other.

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Reducing Vulnerability: The Role of Tank Camouflage Measures

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CACDA

ABSTRACT: The state of military weaponry and target detection capability is such that combat developers perceive the need to provide tanks with unusual and sophisticated camouflage countermeasures to reduce electromagnetic signatures.

Currently existing target acquisition devices can detect tanks to distances greater than the maximum effective main gun range. To afford the tank commander a measure of reduced vulnerability, a number of specific camouflage measures were tested and evaluated. During the process of evaluation, several fundamental questions were addressed; specifically (1) What are the signature cues that cause the tank to be detected, (2) What, if any, camouflage measures reduce the tank's signature, (3) Under what conditions may camouflage measures usefully be employed, and (4) Will camouflage measures significantly effect the outcome of battle?

Field testing indicated that specific camouflage measures substantially reduced the range to detection of the stationary tank during the day, against all types of sighting devices tested. At night, camouflage measures proved effective in reducing the range to detection of the stationary tank against image intensifier (I^2) devices, but not against other types of sighting devices. The effects of camouflage on the outcome of battle have yet to be quantified satisfactorily due to (1) limitations inherent in existing simulation models and (2) the unknown relationship between firing and nonfiring acquisition rates of camouflaged and noncamouflaged tanks. Mathemetical modeling has provided valuable insight into the military worth of camouflage by indicating trends in battle outcomes.

REDUCING VULNERABILITY -- THE ROLE OF TANK CAMOUFLAGE MEASURES

The Army's Field Manual 100-5 states that the Army must be prepared to fight outnumbered and win. Moreover, Army units will have to function effectively in an environment in which a variety of electronic and optical countermeasures may be employed. To be successful against a well-equipped, numerically superior enemy, the Army needs equipment which is technologically superior, not only in terms of munitions and firepower, but also in terms of survivability. Thus, the materiel developer has the dual objective of increasing enemy casualty rates through increased weapons effectiveness and decreasing US casualty rates through programs aimed at enhancing survivability.

In keeping with the objective of enhancing the survivability of Army equipment, TRADOC and DARCOM have established a joint program in the area of countersurveillance. The pilot effort of the countersurveillance program dealt with camouflage applications to the M60A1 tank. The tank camouflage program, which was managed jointly by MERADCOM (the DARCOM representative) and CACDA (the TRADOC representative), has a twofold objective: (1) investigate the applicability of current camouflage technology to improve the survivability of the tank on the battlefield; and (2) document a complete case of camouflage application, test, and evaluation so that other elements in DARCOM and TRADOC would have a pilot program which could be used for camouflage planning of other systems. Work on the tank camouflage program was divided into the following subtasks:

TASK	RESPONSIBLE AGENCY
Identification of Threats	CACDA
Development of Camouflage Techniques	MERADCOM
Application of Camouflage Techniques	TACOM
Testing	TECOM
Military Worth Analysis	CACDA
Technical Assessment	MERADCOM
Overall Report	MERADCOM/CACDA

Based upon inputs by CACDA, the following detection devices were used, as appropriate, during various trials of the actual tank camouflage test.

AIDED VISUAL DEVICE	THERMAL DEVICES
M-19 Binoculars	TOW Thermal Sight
M105D Tank Telescope	
TOW (day sight)	
M47 Dragon (day sight)	
M32/M35 Series Tank Periscope with Passive and IR Elbow	

Summary of Camouflage Applications Test

The overall objective of the camouflage test conducted by TECOM was to generate the data required by the Countersurveillance Laboratory of MERADCOM as input for their technical assessment of camouflage effectiveness and to generate data required by CACDA as input to their statistical and military worth analyses of camouflage. Specific test objectives included the requirement for generating data necessary for determining the following measures of performance (MOP):

a. The time and range to detect, to recognize/identify and to acquire the camouflaged and uncamouflaged M60A1 tank by trained observers using visual ground sensors.

b. The probability of detection, of recognition/identification and of acquisition by trained observers as a function of time and range against visual ground sensors.

Testing was conducted by the Materiel Testing Directorate, Aberdeen Proving Ground, using equipment and facilities at APG during the period 20 April 1976 to 11 August 1976. Technical guidance and assistance was provided by USAHEL as pertained to the aerial observation of the camouflaged and uncamouflaged M60A1 tanks. Subtests conducted at Aberdeen Proving Ground addressed both ground and aerial surveillance of a camouflaged test tank and a pattern painted control tank. Initial application of fixes to the camouflaged test tank were made at Aberdeen Proving Ground by personnel from MERADCOM and from the US Army Tank Automotive Research and Development Command (TARADCOM). In addition, an initial inspection, a human factors subtest, a maintenance evaluation, and a safety subtest were conducted.

The following variables comprised the environmental profiles of the ground surveillance phase of the test:

a. Terrain (flat and rolling).

b. Vegetation (light and heavy).

c. Range (up to 3000 meters).

d. Visibility (clear to limited).

e. Time (day and night).

f. Tactical mode of target (moving and stationary).

Three approach modes were used by military observers who were trained in the detection and recognition/identification of targets and who were also familiar with the sighting devices used. The specific sighting devices and/or associated weapons and the corresponding approach modes addressed are shown in Table 1. Observers received refresher training from USAAPMC instructors preliminary to start of the field tests.

TABLE 1. GROUND SURVEILLANCE OBSERVATION PARAMETERS

WEAPON/SIGHTING DEVICE	DET/ID	ACQ	APPROACH MODE TRACKED	WHEELED	GROUND	DAY	NIGHT
1. Unaided Eye	X		X	X	X	X	X
2. 7x50-mm Binocular	X		X	X	X	X	X
3. M105D Tank Telescope	X	X	X			X	X
4. M32/35E1 Tank Periscope	X	X	X			X	
(a) w/Passive Elbow	X	X	X				X
(b) w/IR Elbow	X	X	X				X
5. TOW	X	X		X		X	
(a) w/AN/TVS-5	X	X		X			X
(b) w/Thermal Sight	X	X		X			X
6. M47 DRAGON	X	X			X	X	
7. M67 90-mm Recoilless w/AN/TVS-5	X	X		X			X
8. M79 Grenage Launcher w/AN/PVS-4	X	X			X		X

Approaches were made by the observers in pseudo-tactical team configurations using the designated mode of transport. Each observer team was supported by a driver and by a data collector/recorder and communications person. Test procedures assured that both the camouflage and pattern-painted tanks would be observed in nearly identical settings so as to validate any comparisons made between them. Other pattern-painted distractors (APC, M109 Howitzer, 3/4-ton truck) were incorporated into target arrays.

For the ground surveillance trials, each observer team (consisting of one primary observer and one secondary observer) began its approach from the specified maximum range. The primary observer attempted to detect the tank targets with the designated sighting device during a given search period along the approach route. If a target was not detected during the search period, the observer broke visual contact with the sighting device, the observer team continued in its approach by moving forward incrementally

along the approach route, and the primary observer resumed search. Such incremental moves were deemed necessary due to the inability of the observers to see through the sights while moving. The observer team continued in tis approach until both the camouflaged and pattern-painted tank were detected/identified/acquired.

All ground observations of dynamic targets were made by stationary observers from preselected observation posts. During dynamic target trials, target tanks made intermittent stops. Moving distractors were also used in these target trials.

In the aerial surveillance phase, test sites were from the same areas as those used in the ground observation tests. An OH-58 helicopter was used in both the nap of the earth route reconnaissance and pop-up flight modes in accordnace with current tactical practice of the air cavalry. Ten qualified US Army pilots were used as aerial observers. During the aerial phase of the test the camouflaged test tank and the pattern-painted control tank were deployed only in the static mode. Observations were made under conditions of clear visibility both day and night. Special eye-movement cameras developed by USAHEL were used to record what was actually seen by observers.

The initial data provided for the accomplishment of ground surveillance statistical and military worth analyses were obtained from individual and summarized data sheets comprised of range and time data recorded during each trial execution. The range data consisted of the range of tank target detection/identification/acquisition. The time data consisted of the time to detect/identify/acquire each target from the time the observer began search at the detection/identification/acquisition range. Since these times did not reflect the total time it took the observer to detect/identify/acquire each target from trial start, a request was made to the testing agency to provide the total cumulative search times for all test trials. With some exception, these cumulative times were provided by the Materiel Testing Directorate, APG. Table 2 depicts the distribution frequency of ground surveillance data and correlates the environmental profiles of the test trials with the three approach modes, different sighting devices, and groups of test data provided for analysis. The four categories of test data are:

a. day/stationary

b. day/moving

c. night/stationary

d. night/moving

		DAY STATIONARY VEGETATION/TERRAIN											DAY/MOVING VEGETATION/TERRAIN										
		Light/Flat					Light Rolling						Light Flat				Heavy Rolling						
		Maximum Range(M) 3,000 (data gp 1)					Maximum Range (M) 2,000 (data gp 3) 3,000 (data gp 10)						Maximum Range(M) 2,000 (data gp 5)				Maximum Range (M) 2,000 (data gp 2/11)[a]						
		Test Site					Test Site						Test Site				Test Site						
		R		Q			T				Y		S				X				Y		
		Target Array					Target Array						Target Array				Target Array						
Approach Mode	Sighting Device	1	2	1	2	3	1	2	3	4	1	2	1	2	3	4	1	2	3	4	1	2
GROUND	Unaided			4	4	1			5	4			1		4	6	5	5	3	4		
	Binocular	6	4				5	5			5	5	5	5			5	5		1	5	4
	TOW														5	5						
	DRAGON			4	4	1			5	6												
	Periscope																					
	Telescope																					
	NVD (RR)																					
	NVD (GL)																					
WHEELED VEHICLE	Unaided			6	6				5	5					5							
	Binocular	6	5				5	5			5	5	5	5			5	5	5	5		
	TOW				6	4			5	5					5	5					5	4
	DRAGON																					
	Periscope																					
	Telescope																					
	NVD (RR)																					
	NVD (GL)																					
TANK	Unaided																					1
	Binocular	5	5				5	5			5	5	5	5			5	5	4	1	5	4
	TOW																					
	DRAGON																					
	Periscope	5	5						6	5					5	5			1	3		
	Telescope																					
	NVD (RR)																					
	NVD (GL)																					

		NIGHT/STATIONARY VEGETATION/TERRAIN									NIGHT/MOVING VEGETATION TERRAIN	
					Light/Rolling				Heavy/Rolling		Heavy Rolling	
		Maximum Range(M) 2,000 (data gp 8)			Maximum Range (M) 3,000 (data gp 4)				Maximum Range(M) 2,000 (data gp 6)		Maximum Range(M) 1,000 (data gp 7)	
		TEST SITE			TEST SITE				TEST SITE		TEST SITE	
		U		V	U				V		W	
		Target Array			Target Array				Target Array		Target Array	
Approach Mode	Sighting Device	1	2	1	1	2	3	4	1	2	1	2
GROUND	Unaided				6	4	4	8				
	Binocular	5	5						5	5	5	5
	TOW											
	DRAGON											
	Periscope											
	Telescope											
	NVD (RR)											
	NVD (GL)	5	10	9	6				5	5	5	5
WHEELED VEHICLES	Unaided											
	Binocular				6		3	2				
	TOW	5	10	9	7				5	5	5	5
	DRAGON											
	Periscope											
	Telescope											
	NVD (RR)	5	5						5	5	5	5
	NVD (GL)											
TANK	Unaided											
	Binocular											
	TOW											
	DRAGON											
	Periscope	5	5	9	6		2	6	5	5	5	5
	Telescope											
	NVD (RR)											
	NVD (GL)		5									

a. Reflects the pooling of data groups 2 and 11, Table 3 because of data similarity

Table 2. M60A1 Camouflage Test Design Matrix, Distribution Frequency of Ground Surveillance Data

Test Results

Ground Surveillance. Detection range data were used to draw inferences about the value of camouflage for tanks under the four types of situations mentioned above. The general findings on the effect of camouflage are summarized by the following matrix.

		TIME OF DAY	
		DAY	NIGHT
Tank Operational Mode	Stationary	Significant	Device Dependent
	Moving	Not Significant	Not Significant

Under day/stationary conditions, the camouflage applications significantly reduced the range to detect/identify/acquire the camouflage tank, compared to the pattern-painted tank, regardless of sighting device used. However, under day/moving conditions, the resulting movement, dust, and noise signature cues nullified the effect of the camouflage applications. When moving, no significant difference in detection ranges between the camouflaged test tank and pattern-painted control tank was found.

Under night/stationary conditions, the camouflage applications were determined to be effective in concealing the tank against I^2 type devices only. The range to detect/identify/acquire the camouflaged tank was significantly less than the range to detect the pattern-painted tank when visual, near IR or thermal devices were used. In the night/moving mode the effectiveness of camouflage was negated by the movement, noise, and heat signature cues of the tank. Under night/moving conditions, there was no significant difference in detection ranges between the camouflaged and pattern-painted tanks regardless of device used.

Aerial Surveillance. Table 3 depicts the means and standard deviations of both day and night aerial surveillance trials. Under daylight conditions, the observers, employing "pop-up" tactic, detected/identified the pattern-painted tank in 9 of 10 trials at an average slant range of 867 meters and an average time of 51 seconds. In one trial, the pattern-painted tank was not found. The camouflaged tank was detected in 4 of 10 trials at an average slant range of 858 meters. However, the average time to detect these 4 tanks was 137 seconds. This difference in average times to detect/identify the two tanks was the result of additional "pop-ups" required to locate the camouflaged tank. In 4 of the 10 trials the camouflaged tank was not found after a total search time per tank of 180 seconds. One additional trial resulted in lost data, and one trial was aborted due to aircraft malfunction.

Table 3. Summary Statistics of the Aerial Surveillance Test Trials

SUMMARY STATISTICS

DAY TRIALS								
TACTIC	TANK	SLANT RANGE (m)			TIMES			PROBABILITY OF DETECTION
	TYPE	NO.	AVG	STD DEV	NO.	AVG	STD DEV	
POP-UP	CAM	4/8	858	.50	4/8	95.0	45.3	.50
	PP	9/10	867	.73	9/10	50.8	42.3	.90
ROUTE RECONNAISSANCE	CAM	8/10	319	162	8/10	74.5	10.2	.80
	PP	10/10	710	337	10/10	38.3	15.2	1.00

SUMMARY STATISTICS

NIGHT TRIALS								
TACTIC	TANK	SLANT RANGE (m)			TIMES			PROBABILITY OF DETECTION
	TYPE	NO.	AVG	STD DEV	NO.	AVG	STD DEV	
POP-UP	CAM	2/5	721	.50	2/5	67.0	53.7	.40
	PP	4/5	723	2.80	4/5	102.5	28.7	.80
ROUTE RECONNAISSANCE	CAM	4/5	557	292	4/5	62.8	10.2	.80
	PP	3/5	515	309	3/5	58.9	10.1	.60

During daylight conditions, the route reconnaissance tactic resulted in quicker detection/identification times than the "pop-up" tactic (an average of 38 seconds to detect the pattern-painted tank and 74 seconds to detect the camouflage tank), and the slant ranges were less than those for the "pop-up" tactic (an average of 710 meters for the pattern-painted tank and 319 meters for the camouflaged tank). The pattern-painted tank was detected/identified in all test trials, and the camouflaged tank was detected/identified in 8 out of 10 tirals.

For daytime conditions, the difference in average slant ranges and times to detect/identify the camouflage and pattern-painted tanks were found to be statistically significant. It was found that in each case the detection probability was significantly higher for the pattern-painted tanks based on the experiment which was conducted.

When the "pop-up" tactic was used under nighttime conditions, and when night vision goggles (NVG) were used as an aid to observation, the pattern-painted tank was detected/identified in 4 of 5 trials and the camouflaged tank in 2 of 5 trials. Using the route reconnaissance tactic and NVG, the pattern-painted tank was detected/identified in 3 of 5 trials and the camouflaged tank was detected in 4 of 5 trials. It was reported that glare from the aircraft instrument lights and canopy reflections hindered observation with the NVG.

Without the use of NVG at night, only one detection was made in the 10 trials using the "pop-up" tactic and the 10 trials using route reconnaissance tactics. The single detection was made using the "pop-up" tactic and was of a camouflaged tank.

Analysis Methodology and Test Results

Analysis Methodology. The analysis methodology for the data derived from the tank camouflage test is based primarily on a paired comparison (sign) and, secondarily upon a paired difference test. During the TECOM test a total of thirty-seven separate experiments were performed for the purpose of determining the worth of camouflage for ground operations. Test configurations represented differences in the time-of-day (day/night), tank mode (stationary/moving), and the type of sighting device. Specific testing configurations are depicted in Table 4. For a given test configuration the statistical test involved obtaining pairs (X_i, Y_i) of observations from a number (N) of observers $(1 \leq i \leq N)$. The number N of observers varied from test to test. Each observer was required to find a camouflaged tank and a pattern-painted tank under the conditions of the specific test. The ranges to detect were noted as test outcomes (X_i, Y_i) for the pattern-painted control and camouflaged test respectively.

	DAY/STATIONARY		DAY/MOVING		NIGHT/STATIONARY			NIGHT/MOVING
DETECTION DEVICE	GP 1	GP 3	GP 5	GP 2	GP 8	GP 4	GP 6	GP 7
UNAIDED EYE	$Z = 3.71$ S	$Z = 2.68$ S	$t_{14} = .56$ NS	$t_{16} = .53$ NS	*	$t_{11} = .46$ NS	*	*
BINOCULAR	$Z = 2.33$ S	$t_{28} = 2.88$ S	$t_{26} = -.22$ NS	$t_{59} = -.33$ NS	$t_9 = -.94$ NS	$t_{11} = .24$ NS	$t_6 = .15$ NS	$t_2 = -.30$ NS
TOW	$t_9 = 1.92$ S	$t_9 = 3\text{-}10$ S	$t_9 = -.89$ NS	$t_6 = .03$ NS	$t_{14} = .85$ NS	$t_{12} = -.4$ NS	$t_8 = -2.73$ NSa	$t_8 = -.20$ NS
DRAGON	$Z = 2.32$ S	$Z = 2.53$ S	$t_9 = .12$ NS	*	*	*	*	*
PERISCOPE (IR)	$Z = 3.16$ S	$Z = 2.53$ S	$t_9 = .78$ NS	$t_3 = .98$ NS	$t_9 = 1.88$ S	$t_{16} = .12$ NS	$t_6 = .23$ NS	$t_6 = -.71$ NS
NVD	*	*	*	*	$t_{28} = 3.75$ S	$t_{11} = 2.91$ S	$t_{17} = 1.47$ S	$t_{12} = 1.02$ NS

S - statistically significant difference between camouflage and pattern-painted detection ranges.
NS - not statistically significant
Z - paired comparison (sign) test value
t - paired difference test value
$\Big\}$ level of significance was .1 in all cases
GP - groups of test data, by specific environmental profile shown in Table 2.
* - no test trials run

a - this computed value of the t-statistic is significant in favor of the pattern-painted tank

Table 4. Experiments Performed and Computed Values of Test Statistic for Camouflage and Pattern-Painted Detection Ranges.

For the purpose of statistical analysis, the pairs (X_i, Y_i) obtained from an observation were viewed as random variables from a single population. X_i represented the outcome of the ith trial for the pattern-painted tank and Y_i the corresponding outcome for the camouflaged tank. To determine whether or not the range to detect the camouflaged tank was less than the range to detect the pattern-painted tank, a paired difference (sign) test was first applied as a preliminary screening device. The mechanics of the sign test were as follows:

a. For each observation (X_i, Y_i), $X_i - Y_i$ was computed to determine whether $X_i - Y_i > 0$ or $X_i - Y_i < 0$.

b. The fraction of successes was then determined (obtained as the ratio of the number of trials resulting in $X_i - Y_i > 0$ to the total number of trials).

c. The null hypothesis was assumed to be $P = \frac{1}{2}$, where P is the true proportion of times that $X - Y > 0$ holds over the universe of all possible observers. The null hypothesis expresses the fact that $X - Y > 0$ happens by chance.

d. The alternate hypothesis was assumed to be $P > \frac{1}{2}$. The alternate hypothesis was determined to be true if in fact the detection of the camouflaged tank was harder to make than the detection of the pattern-painted tank (on a statistical basis).

e. The test statistic was $Z = \frac{k/N - \frac{1}{2}N}{\sqrt{N/4}}$, where k is the number of observations for which $X_i - Y_i > 0$, and N is the total number of observations.

f. The null hypothesis was rejected if $Z \geq 1.28$. Thus, the test is a one-tailed test at the 90% significance level. Rejection of the null hypothesis means that the proportion of outcomes with $X - Y > 0$ is significantly greater than $\frac{1}{2}$.

If the null hypothesis is rejected using the paired comparison test, it will be rejected using more stringent tests such as the paired difference test. Therefore, when the paired comparison testing resulted in rejection of the null hypothesis, no further statistical testing was required. The paired comparison test is an attractive screening device because it is computationally simple to perform. However, in the event that the null hypothesis is not rejected using the paired comparison test, a more powerful test is appropriate.

For the cases in which the null hypothesis was not rejected using the paired comparison (sign) test, a paired difference test was performed. The paired difference test is more powerful (i.e., there is a reduced chance of incorrectly accepting the null hypothesis). Basically, the

additional power of the paired difference test results from more stringent use of the sample data. The sign test is only concerned with whether a pattern-painted tank is observed at a greater range than a camouflaged tank. The paired difference test makes use of the magnitude of the range differences in addition to the algebraic sign.

The procedure for applying the paired difference test is the following:

a. For each (X_i, Y_i) pair obtained in a given experiment, the detection range difference, $d_i = X_i - Y_i$, is computed. It is assumed that each d_i is normally distributed with the same unknown variance V^2.

b. The sample mean $\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n}$ and the sample variance

$$S^2 = \frac{\sum_{i=1}^{n} (d_i - \bar{d})^2}{n-1} \quad \text{are computed.}$$

c. The null hypothesis for the paired difference test is that d = 0; that on the average there is no difference between the range to detect a camouflaged and a pattern-painted tank. The alternate hypothesis is $d > 0$, meaning that the range to detect a pattern-painted tank is greater than the range to detect a camouflaged tank.

d. The test statistic for the paired difference test is

$$t_{n-1} = \frac{\bar{d}}{\sqrt{S^2/n}}$$

which, under the assumptions of the null hypothesis, is a t-distribution with n-1 degrees of freedom.

e. The null hypothesis is rejected if $t_{n-1} > T_{.1,\, n-1}$, where $T_{.1,\, n-1}$ is found from a standard table of t-distribution values for n-1 degrees of freedom and a significance level of .1.

Test results. The results of the statistical test are given in Table 4. Each column of table 4 shows the statistical findings of experiments performed at a particular test site under the specified mode (stationary/moving) and time-of-day (day/night). Each row gives the results of experiments using a particular type of sighting device. Each cell contains either a Z-entry or a t_{n-1}-entry, and either an NS or an S entry. The t or Z value is the computed value of the appropriate statistic as described above. The NS or S designation is an abbreviation for "not statistically significant" or "statistically significant," respectively.

Invariably, a computed Z-statistic in a given cell will be accompanied by an S designation. The presence of a t-statistic value indicates that the corresponding Z-value as obtained from the sign test did not yield statistically significance (that is, $Z < 1.28$ resulted).

For each day/stationary experiment, the range to detect a pattern-painted tank was significantly greater than the range to detect a camouflaged tank, independent of the type of sighting device used. In the day/moving and night/moving cases, no significant differences were detected between the ranges to detect camouflaged and pattern-painted tanks. In the night/stationary case, the range to detect the camouflaged tank was significantly less than the range to detect the uncamouflaged tank when I^2 (night vision) devices were used. A significant difference was also noted in one specific test (data group 8) using the IR periscope.

The latter experiment is worth discussing in some detail, as one might wonder why a significant difference in detection ranges appeared at one test site and not at the others, using a periscope. One should note first that the data group 8 test data consisted of only 10 pairs of observations, giving an inference based upon a small sample size. A close examination of the completed values of the d-statistic ($d_i = X_i - Y_i$), reveals the existence of an outlier -- a computed d-value which is 2.4 standard deviation units from the sample average d. If the t-statistic is recomputed excluding the outlier, the resulting t-value is not significant at the .1 level. Thus, it appears that camouflage does not significantly reduce the visual effectiveness of the IR periscope at night.

Tables 5 and 6 provide summary statistics pertaining to detection ranges. Table 5 shows, for each test situation, the difference in the average range to detect the pattern-painted tank as compared to the average range to detect the camouflaged tank. A cell contains an asterik (*) if no test was performed using the corresponding test site/mode/time/sighting device. When a cell contains a zero, no significant difference in detection ranges was found for the corresponding test. A positive or negative entry in a cell indicates the signed difference in detection ranges, given the existence of a significant difference. A positive entry indicates that the range to detect the camouflaged tank was shorter than the range to detect the pattern-painted tank. A negative entry indicates that the range to detect the pattern-painted tank was shorter than the range to detect the camouflaged tank. Table 6 shows the average range to detect pattern-painted tanks for the appropriate test site/mode/time/sighting.device. The figures in parentheses indicate the number of test trials per cell.

MILITARY WORTH ANALYSIS

The results of the previous section show that in the day/stationary mode, camouflage is an effective countersurveillance measure, in the sense that it reduces the mean detection range. However, the intrinsic value

DETECTION DEVICE	DAY/ STATIONARY GP1	DAY/ STATIONARY GP3	DAY/ MOVING GP5	DAY/ MOVING GP2	NIGHT/STATIONARY GP8	NIGHT/STATIONARY GP4	NIGHT/STATIONARY GP6	NIGHT/ MOVING GP7
UNAIDED EYE	656	398	0	0	*	0	*	*
BINOCULAR	357	458	0	0	0	0	0	0
TOW	630	495	0	0	0	0	-273	0
DRAGON	734	699	0	*	*	*	*	*
PERISCOPE (IR)	712	473	0	0	131	0	0	0
NVD (I^2)	*	*	8	*	144	243	90	0

Table 5. Difference in Range to Detection Between the Pattern-Painted and Camouflaged Tank

DETECTION DEVICE	DAY/STATIONARY GP 1	DAY/STATIONARY GP 3	DAY/MOVING GP 5	DAY/MOVING GP 2	NIGHT/STATIONARY GP 8	NIGHT/STATIONARY GP 4	NIGHT/STATIONARY GP 6	NIGHT/ MOVING GP 7
UNAIDED EYE	1395 (21)	1270 (20)	1741 (15)	1350 (16)	*	516 (18)	*	*
BINOCULAR	2162 (31)	1673 (29)	1930 (27)	1526 (27)	253 (10)	615 (18)	127 (10)	147 (10)
TOW	1725 (10)	1941 (10)	1902 (10)	1807 (8)	1116 (15)	509 (15)	545 (9)	538 (10)
DRAGON	1617 (9)	1836 (11)	1899 (10)	*	*	*	*	*
PERISCOPE (IR)	2112 (10)	1669 (10)	1929 (10)	1565 (4)	1041 (10)	382 (23)	403 (10)	424 (10)
NVD (I^2)	*	*	*	*	696 (30)	408 (15)	307 (20)	343 (20)

Table 6. Mean Ranges to Detect the Pattern-Painted Tank

of reducing the detection range of a stationary tank is not immediately evident. CACDA was responsible for conducting a military worth analysis to determine, if possible, the effect on the outcome of a battle of camouflaging stationary tanks.

The Battalion Level Differential Model (BLDM) was used as the analytical tool for this study. BLDM is a force-on-force differential model of small unit combat that, for the purpose of this analysis, involved movement and direct fire engagements. Five Blue tanks (M60A1) were defending against 25 Red tanks (T62). There were no other weapons played in the simulations. The following assumptions were implicit in the use of BLDM for the military worth analysis:

a. There is no loss of synergistic effects resulting from playing a purely tank-on-tank battle.

b. BLDM portrays the data realistically written the bounds of a yes/no answer. That is, the model will not lead to false conclusions with respect to the worth (or lack thereof) of camouflage. It is not necessarily assumed that the model realistically portrays the extent of the value of camouflage.

Although the BLDM model used in the camouflage analysis was believed to provide a credible representation of the qualitative effects of camouflage, it was not considered useful for obtaining order of magnitude relationships, for two reasons. First, a satisfactory emperical model of sector search was not available at the time of the analysis. Thus, the BLDM model assumed that all targets having physical line of sight with an observer are within his sector of search, and are equally likely to be examined during a given search period. Thus, acquisition rates in the model were unrealistically high. Moreover, the BLDM model differentiated between acquisition of firing and nonfiring targets.

It was hypothesized that the probability of not acquiring a firing target decreases geometrically with the number of rounds fired so that in BLDM the firing acquisitions tends to dominate. It should be noted, however, that the procedure used in BLDM to model the acquisition of firing targets had not been validated at the time of the study; specifically, the relationship between firing and nonfiring acquisitions was not addressed during the TECOM test.

Since the precise relationship between firing and nonfiring acquisition was not known, and since no estimate of the probability of acquiring a firing target was available, the procedure which was adopted was "worst case" analysis. It was found that a firing acquisition probability in excess of .3 resulted in no change in the BLDM output. Accordingly, all firing acquisition probabilities which would affect model output were between 0.0 and 0.3. The BLDM model was therefore run using firing acquisition probabilities of 0.0 and 0.3 respectively. An acquisition probability of 0.0 corresponds to total deemphasis of firing acquisitions.

and probability of .3 corresponds, for practical purposes, to a total emphasis of firing acquisition. The model output for the 0.0 case vis-a-vis the .3 case represents the maximum change in battle outcome which could be portrayed by BLDM. The case corresponding to the true value of the firing acquisition probability, was assumed to fall somewhere between.

Figures 7 through 10 compare the outcomes of BLDM battle simulations in which Blue tanks were and were not camouflaged, and in which firing acquisitions were emphasized and deemphasized.

In Figure 7, Blue tanks were not camouflaged and firing acquisitions were emphasized (i.e., all firing Blue tanks were detected by Red forces). The result of the battle was as expected -- heavily in favor of the Red force.

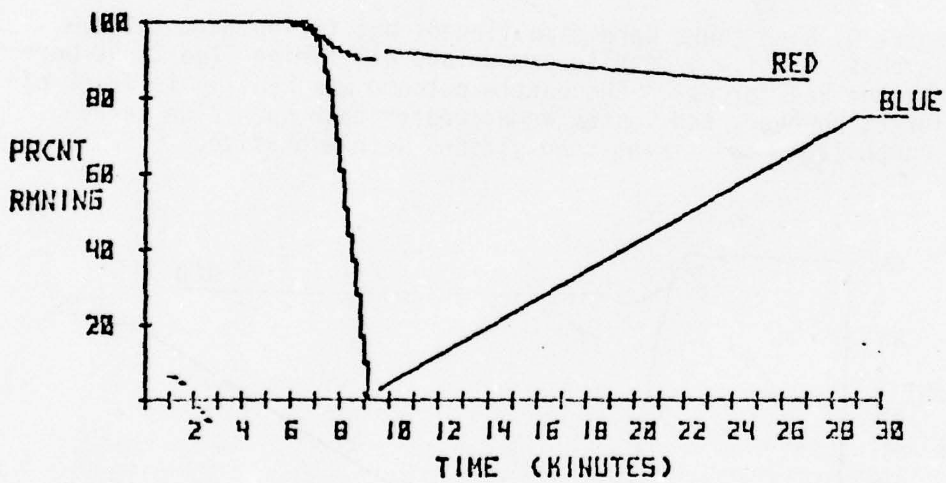

Table 7. Blue Tanks Not Camouflaged/Firing Acquisitions Emphasized.

In Figure 8, Blue tanks remained uncamouflaged, however, firing acquisitions were deemphasized (i.e., even without camouflage, Blue tanks were not detected by Red forces as a result of firing). The battle outcome remained in favor of the Red force but not as significantly as with firing acquisition empahsized.

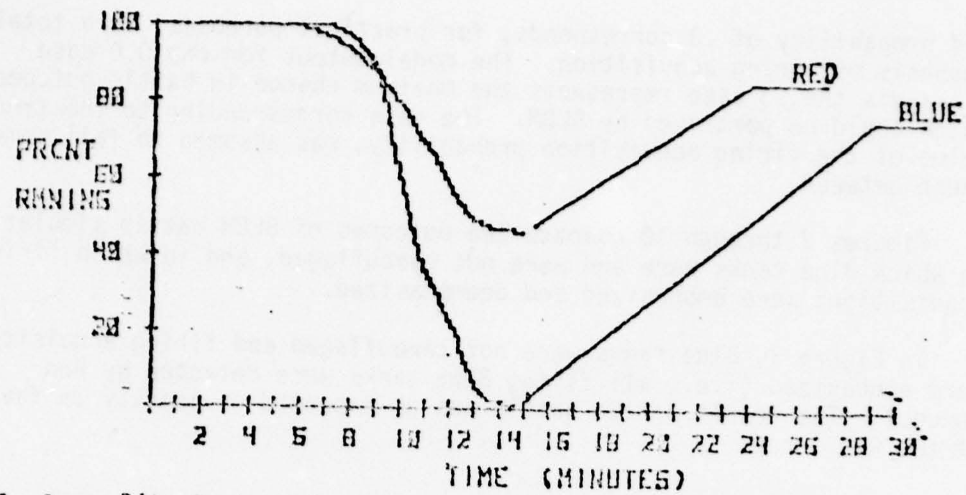

Table 8. Blue Tanks Not Camouflaged/Firing Acquisitions Deemphasized.

In Figure 9, Blue tanks were camouflaged, but firing acquisitions remained emphasized (i.e., despite camouflage all firing Blue tanks were detected by the Red forces). The battle outcome was heavily in favor of the Red force; however, Red losses were greater than when Blue tanks were not camouflaged and firing acquisitions were emphasized.

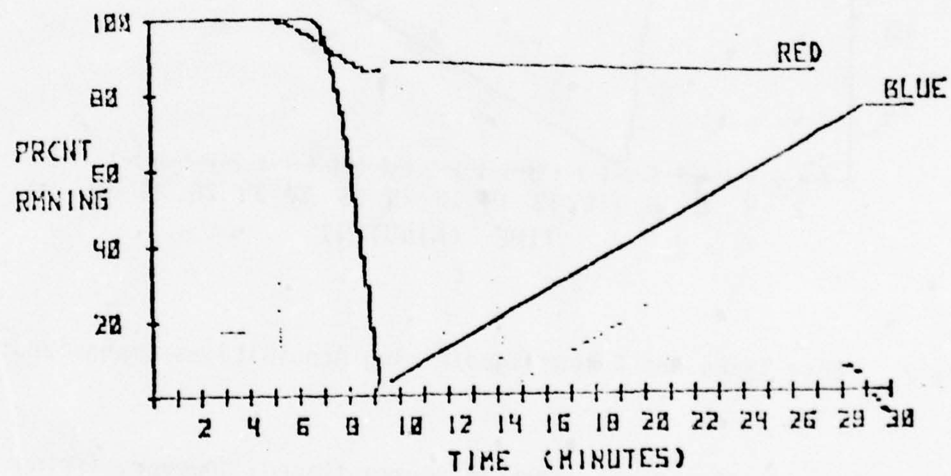

Table 9. Blue Tanks Camouflaged/Firing Acquistions Emphasized.

In Figure 10, Blue tanks were camouflaged and firing acquisitions were deemphasized (i.e., Blue tanks firing were not detected by Red forces). In this simulation, the trend of battle reversed in favor of of the Blue force.

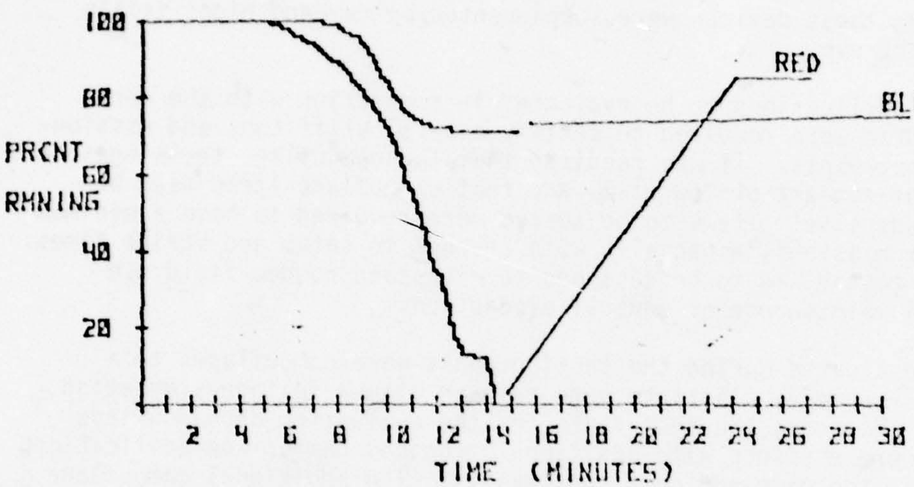

Table 10. Blue Tanks Camouflaged/Firing Acquisitions Deemphasized.

From the foregoing, it is apparent that the military worth of camouflaged tanks on the outcome of these battle simulations consists of both more Red force losses and fewer Blue force losses. However, the magnitude of that contribution cannot be determined without actual firing acquisition rates of camouflaged and noncamouflaged tanks. Once determined, the relationships between the two and its impact on the battle outcome can be established.

AIDED VISUAL DEVICE	THERMAL DEVICES
AN/TVS-5 Crew Served Weapon Night Vision Device AN/PVS-4 Individual Served Weapon Night Vision Device	

Trials using these devices were supplemented by day and night trials using the unaided eye.

Camouflage applications to be evaluated in connection with the tank camouflage program were required to satisfy several stiff cost and mission-performance constraints. It was required that the camouflage techniques be current state-of-the-art or low-risk, and that camouflage items used be simple and inexpensive. Items to be tested were required to have a minimum impact on armor missions, especially with respect to setup and strike times. Hardware to be tested had to be designed to withstand rugged field use without special maintenance or unusual precautions.

All tanks evaluated during the testing phase were camouflaged to a certain extent - namely, all tanks were painted with a foliage-simulating pattern paint. However, the test tanks for the evaluation of camouflage effectiveness were equipped with additional proposed camouflage applications developed within the time and cost constraints. The additional camouflage applications were evaluated as a package during the camouflage effectiveness tests, so that it was not possible from available data to say specifically which of the camouflage measures employed contributed the most to signature reduction or modification. The intent was merely to compare the ease of detection of the tanks with the camouflage package with the ease of detection of the uncamouflaged tanks.

The camouflage applications changed the appearance of the M60A1 tank. Turret and hull signatures were changed by reshaping accomplished with the exhaust deflector, a low profile antenna, and special fender skirts. Disruption of the shape of the vehicle was accomplished by securing natural foliage in foliage brackets and by deploying a gun barrel disruptor, fender nets, and a bustle rack net.

Additional user evaluation of proposed camouflage measures according to the criteria of durability and ease of use resulted in recommendations to eliminate or modify several originally proposed measures. The following specific camouflage applications were finally recommended for further engineering development: (1) fender nets and support systems; (2) gun barrel disrupter; (3) foliage brackets; (4) turret bustle net and support systems; (5) textured surfaces. The fender skirts et al were not recommend as an aid in reducing thermal detection signatures, but were suggested as a potential measure for countering heat-seeking missiles. The low profile antenna proved to be operationally ineffective, so that ultimate adoption of a low profile antenna is dependent upon future engineering developments.

TITLE: THE EFFECT OF TARGET VEHICLE AGILITY ON TANK GUNNERS

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ABSTRACT: The effect of evasive maneuvers and intervisibility segment lengths on the ability of a tank gunner to engage and hit the target is an area of great interest in the Armor community. The complete analysis of the data from the Swedish S-Tank Agility/Survivability (STAGS) Test relates the effectiveness of evasive maneuvers to apparent motion parameters of the target vehicle and to the time available for engagement. One of the more important results to come from the test was the extremely large variation which was found to exist between gunners who had been similarly trained. Included in this paper are comparisons between "good" gunners and "bad" gunners. Their performance against seven different target vehicles with varying horsepower per ton ratios is presented. There was also a large variation within the performance of individual gunners. The implication is that one of the most effective ways to improve the performance of our antiarmor gun systems is through improved performance of the crew.

THE EFFECT OF TARGET VEHICLE AGILITY ON TANK GUNNERS

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1. INTRODUCTION

The United States Army Armor and Engineer Board (USAARENBD) is assisting the Defense Advanced Research Projects Agency (DARPA) in an effort to determine and validate high payoff technologies for the future development of combat vehicles. This assistance is to be rendered in progressive phases of a High Mobility and Agility (HIMAG) Vehicle Program throughout the period calendar years 1975 - 1979. The purpose of Phase I was to evaluate the characteristics, relative advantages, and limitations of the turreted and turretless tank, and to make a baseline assessment of the contribution to vehicle survivability made by mobility and agility.

Phase I experimentation and analysis constituted the S-Tank Agility/Survivability (STAGS) Test conducted in open terrain (YANO Range at Fort Knox). The objectives of the experiment were to obtain data that would provide insights into the effects on vehicle survivability of

- Constant speed
- Rapid start and stop operations
- Evasive tactics
- Target silhouette.

Even though the analysis of firing vehicle crew performance was not an initial objective of the STAGS Test, the results of the experiment dictated that a complete analysis of this factor be conducted. The results of the crew performance analysis are described in this paper. These results are presented as relative evaluations of crew performance for reasons of classification. The complete results of the analyses are given in the Swedish Tank Agility/Survivability (STAGS) Second Partial Report, Project Number 1-C1-000005-03.

2. THE EXPERIMENT

Defender (firer) vehicles were one M60A1 tank, one M60A1E3 tank, one S-Tank, and one TOW tracker. Because the S-Tank was not required to range during the STAGS experiment, the resulting data would not represent its actual ability. Therefore, it is referenced as F1 in the presentation of results. Data was collected using motion picture cameras mounted on the defensive weapon systems to provide data for analysis and evaluation of lay times, lay errors, tracking accuracies, miss-distances, etc., for each defender's engagement against the target vehicles. A position location system was used to collect time and range-to-targets while software conversions provided position vectors, target

vehicle speeds, accelerations, and apparent motion parameters. The results presented in this paper are based on the M60A1 (A1) and F1 firer vehicles only.

Seven target vehicles were used to provide a wide range of horsepower/ton ratios and included: M60A1 tank (14 hp/ton); S-Tank (17 hp/ton); M113A1 (21 hp/ton); ARSV track test bed (36 hp/ton); German RVT-2 (63 hp/ton); Twister Test Bed (68 hp/ton); and M113/2E (with 2 engines, 79 hp/ton).

Three courses (400 meters in length) were selected for target movement. The first was a constant range, flank course at 1,900 meters from the firers. The second was an oblique (approaching) course beginning at 2,000 meters range and ending at 1,800 meters. The third course was a head-on course beginning at 1,100 meters.

Several evasive tactics were evaluated over each course. These tactics included:

Constant Speed. Target vehicles accelerated to a given speed and maintained that speed throughout the run. (Speeds were 15, 30, and 45 mph).

Dash-to-Cover (D). Target vehicles maintained all-out acceleration over the test course.

Long Sine (LS). Target vehicles maneuvered on a marked course with a full period length of 250 meters and an amplitude of 10-12 meters.

Original Damped Sine (ODS). Target vehicles maneuvered on a marked course consisting of three sines with a "dampening" effect (sine 1 had 90-meter periods, 15-meter amplitude; sine 2 had 60-meter periods, 10-meter amplitudes; sine 3 had 30-meter periods, 8-meter amplitude).

Modified Damped Sine (MDS). Target vehicles maneuvered on a dampened sine as above, with modifications to the periods and amplitudes.

Free Play (FP). Target vehicles executed random evasive maneuvers over the course run.

Five crews were used on each defender vehicle for each course-maneuver-target combination. While the number "five" did not constitute a "large" sample size for each combination, this number of iterations was intended to assist in "averaging" out sources of variation in the experiment outcomes caused by variability between gunners.

3. CREW ANALYSIS

The objectives of the analysis of defender vehicle crew performance were

- To determine the amount of variation between crews for each firer.

- To investigate the possibility of a learning effect during the experiment.

- To assess the implications of differences in crews upon other conclusions from the test.

The Armor and Engineer Board was provided with five M60A1 crews. A pretest check indicated that these crews would benefit from additional training, which was provided. Twenty-one men were selected to be trained as S-Tank crewmen. They were above average in motivation and past performance. They were "good soldiers" with a high probability of completing the intensive six-weeks special training and the following STAGS test. Because there was no cross training of crews (i.e., crews trained and "fired" only one vehicle), the method of analysis included split plot analyses of variance with crews treated as sub plots. Means were tabled and graphed, trend lines were plotted and learning effects were investigated.

The term "crew" is used throughout this paper. It should be noted that for the F1 firer, the gunner was the sole contributor to the results. For the A1 firer, the tank commander had some influence (he determined range) but primarily the gunner was responsible for the results.

The analysis of variance indicates that for most variables the ERROR A mean squares are much larger than the ERROR B mean squares. ERROR A is made up of variability due to CREW and CREW/FIRER interaction, and ERROR B is the "within plot" residual error. Although there is no appropriate statistical test to evaluate crew differences in this design, the fact that the ERROR A is so much larger than ERROR B indicates a great deal of variability between crews. For the entire data base, GXERR (gunner induced horizontal miss distance, the variable of most importance in this paper) has an ERROR A mean square which is 49 times as large as the ERROR B mean square.

An examination of means for the various crew confirms this variability. The performance of each crew versus each target vehicle is shown in figures 1 and 2. The actual magnitude of $|GXERR|$ is not shown for reasons of classification. Note from figure 1 that the error for the worst F1 crew was up to 6 times greater than for the best F1 crew (versus the Twister vehicle). A comparison of figures 1 and 2 indicate a smaller spread between A1 crews than between F1 crews, even though F1 crews were subjected to a much more intensive training program than were the A1 crews. Examination of the figures also indicates

FI CREWS

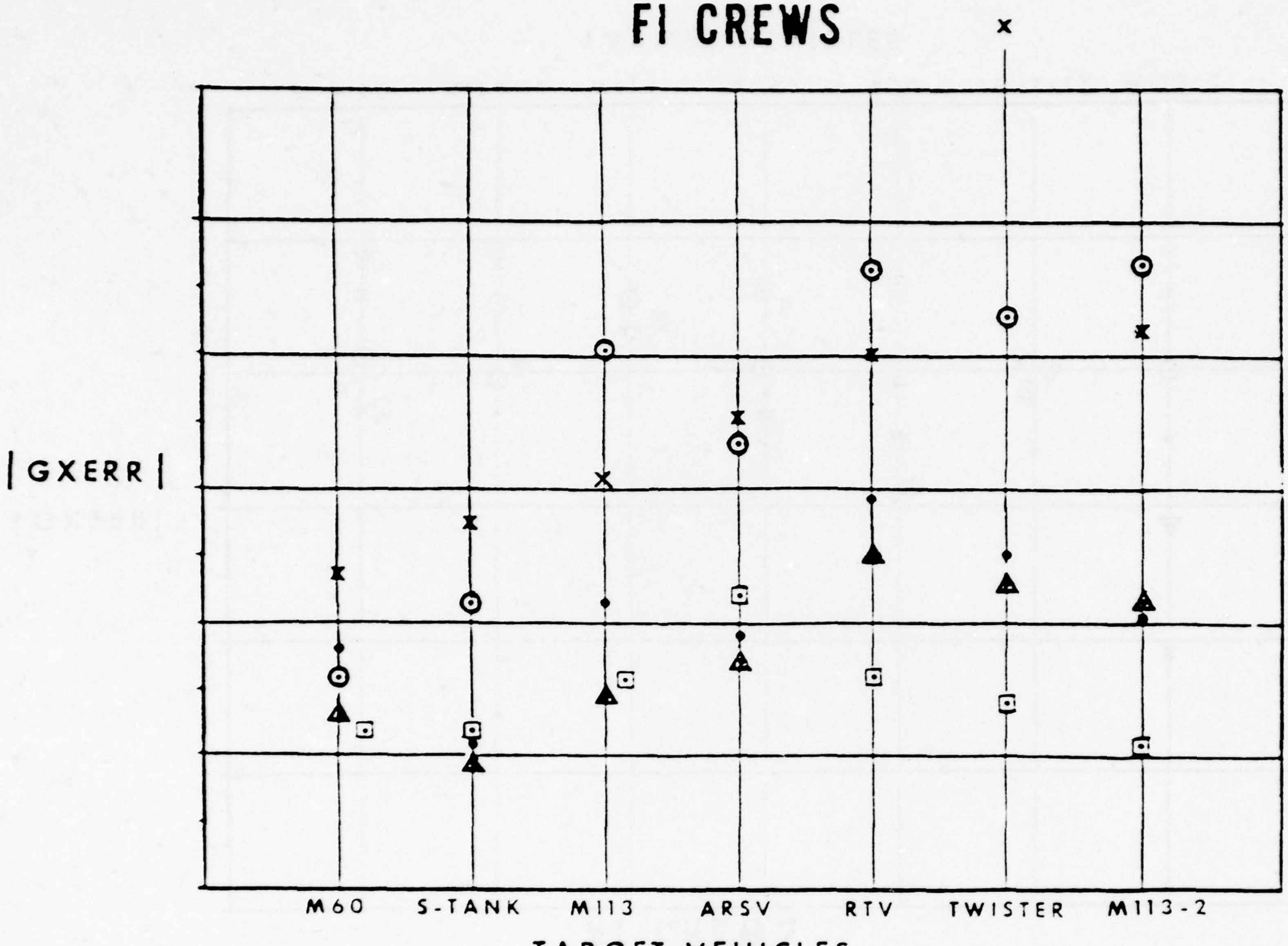

FIGURE 1

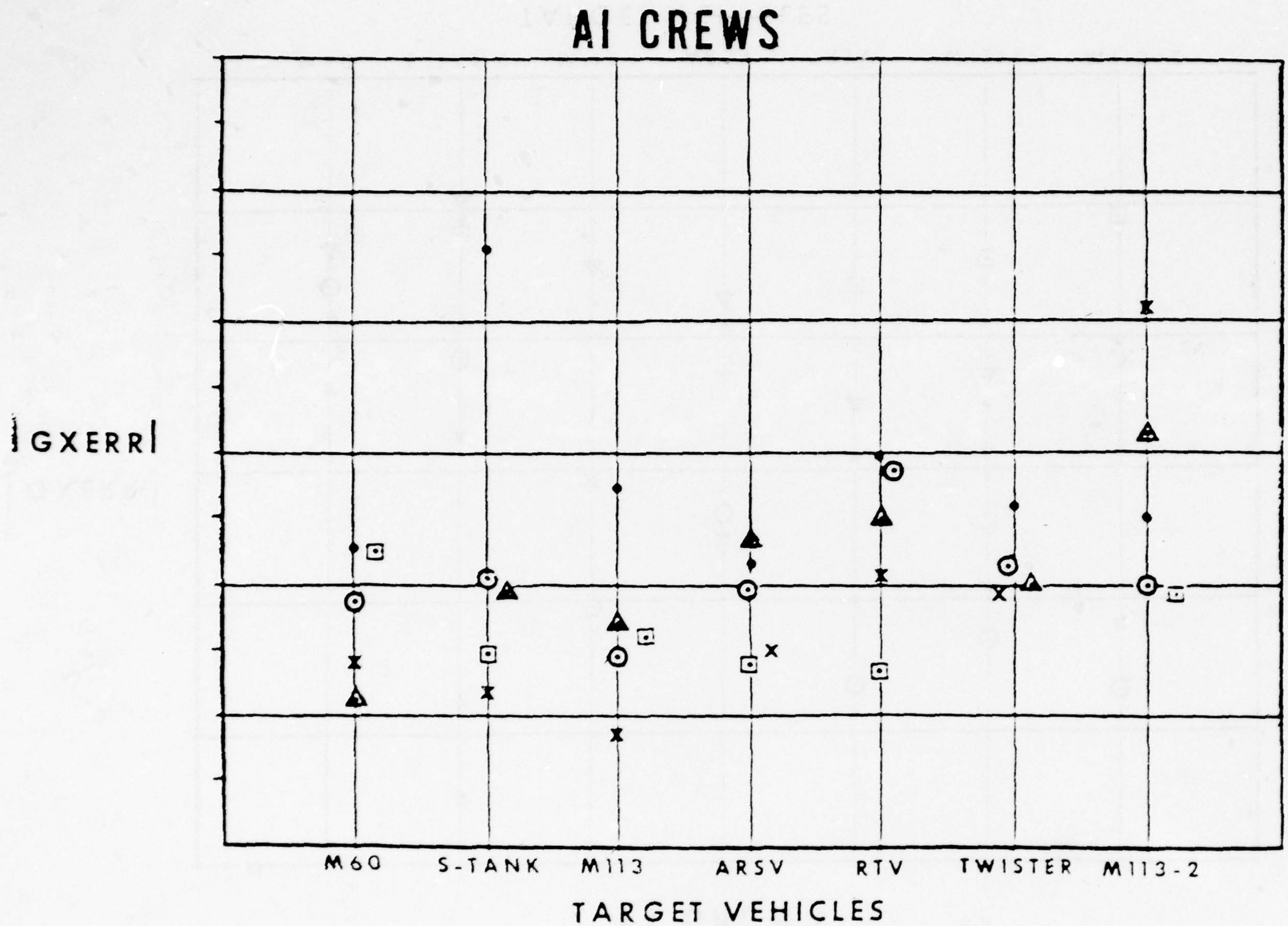
AI CREWS
|GXERR|
M60
S-TANK
M113
ARSV
RTV
TWISTER
M113-2
TARGET VEHICLES

FIGURE 2

a marked consistency (with good crews generally good and bad crews generally bad) regardless of target. A similar pattern resulted from analyses by course and by maneuver.

Recall that GXERR was defined as the gunner-induced contribution to horizontal miss-distance. TXERR was defined as the target-induced contribution to horizontal miss-distance, and

XERR = GXERR + TXERR
where XERR = total horizontal miss distance.

TXERR and |TXERR| values were essentially the same for all crews. This fact lends credence to the data, since the ability of the gunner has no influence on the error induced by a maneuvering target after trigger pull.

Another significant observation from the analysis was that the poorest crews tended to overlead the targets, as reflected by XERR (i.e., the mean value of XERR was a significant positive number). On the other hand, the mean value of XERR for the best crews was very close to zero, indicating no trend toward overleading or underleading.

For each firer vehicle, the crews were ranked for each of the following variables (see figure 3):

- |XERR| - Total horizontal miss-distance
- |YERR| - Total vertical miss-distance
- PH-D - Hit probability considering ballistic dispersion
- PH-B - Zero, one (miss-hit) for a trigger pull
- |GXERR| - Gunner induced horizontal miss-distance
- |TXERR| - Target induced horizontal miss-distance.

Based on these rankings, an overall ranking was subjectively assigned. The overall ranking for F1 crews was clearcut; the overall ranking for A1 crews was not as obvious but was based mainly on |GXERR| and PH-D.

A comparison was made for the F1 crews between the rankings on pretest training performance, subjective observations of crew abilities by a test project officer, and the rankings based on the STAGS test (see figure 4). The correspondence was assuring since those gunners with excellent eye-hand coordination (crews 4 and 1) as measured by pretest training did very well on the STAGS Survivability Test. The one surprise to the test officer was crew 5, which was ranked top on the STAGS test. The gunner did not have the best eye-hand coordination, but the one attribute which apparently compensated for that was high motivation. He was extremely competitive and had an intense desire to "get the job done." Similar information for the A1 crews was not available, since their training was much shorter and less structured.

CREW RANKINGS

ALL COURSES, TARGETS, MANEUVERS

FIRER	VARIABLE	CREW MEMBER BEST				WORST
F1	|XERR|	5	4	1	3	6
	|YERR|	3	4	5	1	6
	PH-B	5	4	1	3	6
	PH-D	5	4	1	3	6
	|GXERR|	5	4	1	3	6
	|TXERR|	5	3	1	4	6
	OVERALL RANK	5	4	1	3	6
A1	|XERR|	5	4	3	2	1
	|YERR|	2	5	3	1	4
	PH-B	5	3	2	4	1
	PH-D	5	3	2	4	1
	|GXERR|	5	4	3	2	1
	|TXERR|	5	3	4	2	1
	OVERALL RANK	5	3	4	2	1

FIGURE 3

FL CREW RANKING

CREW NO.	TRAINING PERFORMANCE	MOTIVATION	STAGS TEST PERFORMANCE GXERR
5	Medium	Very High	1.0x
4	High	High	1.1x
1	High	High	1.3x
3	Medium	Medium	1.8x
6	Fair	Medium	2.1x

NOTE: The mean is expressed using Crew 5 as the baseline 1.0x. All other values are expressed as a multiple of x for reasons of classification.

FIGURE 4

An investigation of possible learning effects for good and bad crews was made. The variable analyzed was |GXERR|. The two best crews and the two worst crews for each firer were compared to see if the learning effects were the same for good and bad crews. The runs under consideration were runs 66 through 345 (all trials except the constant speed runs). Target vehicles and courses were randomized throughout these runs. However, because of test execution constraints (such as changing pylons), the maneuvers were not randomized. All original damped sine and long sine runs were conducted in the first half of the test. All free play and modified damped sine runs were conducted in the last half of the test. The only maneuver which was conducted both at the beginning and at the end was the dash. For this reason, the dash was selected for this investigation. The head-on course was excluded, since it presented no challenge with a dash maneuver.

Means and standard deviations were computed for each run under consideration. The mean |GXERR| for each run was correlated with the exposure number (i.e., first exposure, second exposure, etc.) for the dash for the two crews. Figure 5 lists the mean |GXERR|, the correlation coefficient (r), the probability (p) of getting that extreme an r value if in fact the true correlation was zero and the number (n) of exposures or runs involving the dash for the two crews.

LEARNING EFFECTS ON DASH

FIRER	CREWS	ABILITY	MEAN	r	p	n
F1	5, 4	Good	1.00x	.14	.28	20
F1	3, 6	Bad	1.67x	-.27	.18	14
A1	5, 3	Good	0.82x	.12	.31	19
A1	2, 1	Bad	1.41x	-.02	.48	14

NOTE: The mean is expressed using F1 crews 5, 4 as the base, expressed by x. All other values are expressed relative to x for reasons of classification.

FIGURE 5

The conclusion to be drawn from figure 5 is that there was no learning effect. None of the probabilities are small enough to be significant. For good crews, or bad crews, F1 or A1, there is no evidence that they got better or worse at leading the target as the test progressed. In the absence of any feedback to the crews relative to their "hits," there is no reason to believe that they would get better or worse as the test progressed. Although the r values suggest that the good crews got worse (positive r) and the bad crews got better (negative r), none of the r values are significantly different from zero (no change). A comparison of the means gives an indication of variability between runs. The standard deviation gives an indication of the variability within a run. The standard deviations for good and bad crews on the dash were analyzed to

see if the variability within runs changed as the test progressed. As in the case of means, there were no significant trends in the size of the standard deviations.

Based on the analysis described above, it is concluded that there was no change in gunner performance throughout the Survivability Subtest as a result of a learning effect. There was no change in the mean (average) absolute gunner miss nor in the amount of variability about this mean miss.

In an effort to determine whether good crews and bad crews exhibited the same trends, means and standard deviations were computed for good versus bad crews, broken down by firers, courses, maneuvers, and targets. In every case, trends were found to be the same for the good and the bad crews. Therefore, it appears that the results and conclusions for the Surviability Subtest would not have changed even if the crews had not been so varied.

4. SUMMARY AND CONCLUSIONS

Even though the analysis of crew performance was not a primary objective of the STAGS Test, the results of this analysis are extremely significant and are summarized below:

- The magnitude of the variability both "between" and "within" crews has been quantified from a large data base (approximately 3700 trigger pulls for the F1 and A1 firing vehicles).

- Crew variability is by far the largest contributor to the total experimental variance.

- The "within" crew variance is approximately equal to the mean (for $|GXERR|$), indicating that the poorer crews also exhibit the larger variance.

- The poorer crews exhibited a significant tendency to overlead the targets.

- A significant effort is required in the future to lessen both "between" and "within" crew variance through new training techniques and increased motivation of the crews.

TITLE: A Cost Optimal Approach to Selecting a Fractional Factorial Design.

AUTHORS: CPT William F. Friese, Jr., Department of Mathematics, United States Military Academy; Dr. Douglas C. Montgomery, Georgia Institute of Technology.

ABSTRACT: This research develops a multistage decision process designed to obtain the maximum amount of information from the evaluation of a factorial design while minimizing the amount of resources used in obtaining the information. The use of screening experiments in building the factorial design is investigated in order to maximize the amount of information gained. The use of sequential analysis procedures to terminate experimentation at the earliest possible time is investigated in order to minimize the amount of resources used. The research is limited to 2^n factorial designs involving univariate response models assumed to come from a normal population; however, the procedure can be easily extended to any factorial design.

The approach is demonstrated for an operational test involving a 2^6 factorial design and the results are compared to "classical" procedures. The sensitivity of the required input parameters is investigated and related applications are discussed.

The proposed approach is found to be a viable method of designing, conducting, and evaluating an operational test involving a factorial experiment.

SUBJECT: A Cost optimal approach to selecting a fractional factorial design.

AUTHORS: CPT William F. Friese, Jr., Department of Mathematics, United States Military Academy; Dr. Douglas C. Montgomery, Georgia Institute of Technology.

INTRODUCTION

The U. S. Army Operational Test and Evaluation Agency (OTEA) is tasked with conducting operational testing on items proposed for addition to the Army inventory. Conducting these tests requires the expenditure of a great deal of time and money and OTEA, like every other government agency, is faced with limitations on the amount of rescources available for conducting such tests. As such, they are interested in obtaining the required amount of information concerning the system being tested while expending as few resources as possible. This can be accomplished by minimizing the number of observations or experimental trials required to obtain the desired information.

ASSUMPTIONS

The nature of operational testing often dictates that the tested system be evaluated for several Measures of Effectiveness (MOE), each of which may have to be evaluated at more than one level. As a result, operational testing lends itself very readily to a factorial type experiment. Therefore, this paper will address itself to an experiment involving a factorial design.

Since Operational Testing is designed to test one proposed system against another or against some standard for comparison, the hypothesis to be tested is of the form:

$$H_o: \mu = \mu_o$$
$$H_1: \mu > \mu_o \qquad (1)$$

where μ_o = standard for comparison.
μ = population mean for the item being tested.

Operational testing will require that the prototype item exceed the standard for comparison by a certain margin before the decision to accept the item is made so (1) can be rewritten as:

$$H_o: \mu - \mu_o = 0$$
$$H_1: \mu - \mu_o = \delta\sigma \qquad (2)$$

where d is the required margin of difference.

Since d will be some positive number, it can be expressed as some constant multiple of the population standard deviation, also a positive number, and (2) can be rewritten as:

$$H_o: \mu - \mu_o = 0$$

$$H_1: \mu - \mu_o = \delta\sigma \qquad (3)$$

Given the nature of operational testing, the assumption is also made that the observed responses will come from a normal population with unknown mean μ and variance σ^2. The value of σ^2 may or may not be known and each case will be treated separately. If σ^2 is known, the problem is greatly simplified. If it is not known, a sequential procedure can be developed but an alternate solution is to obtain some estimate of σ^2 as soon as possible. This estimate may be obtained from any prior testing done on the system, from comparison with a similar type system, or from the results obtained in OT I and then used throughout the remaining operational tests.

PROPOSED METHODOLOGY:

This section will present a formalized procedure for building a factorial experiment with the goal of reducing the sample size without reducing the amount of information obtained from the experimentation. This information may include data about the significance of the various factors, the levels of significance, or the probabilities of making a Type I of Type II error. Two cases will be considered, variance known and variance unknown.

Variance Known

If the variance is known, the sequential probability ratio test can be employed to make a decision to either accept the null or alternate hypothesis or to continue sampling. Since (3) is in the form of a simple null hypothesis against a simple alternate hypothesis, the likelihood ratio test:

$$\frac{L_{in}}{L_{on}} = \frac{\sum_{i=1}^{n} F(x_i \mid \theta_1)}{\prod_{i=1}^{n} F(x_i \mid \theta_o)} \qquad (4)$$

can be used as a basis for making this decision. The sequential procedure should include a region for accepting H_o, a region for accepting H_1, and a region in which the decision to continue sampling is made. For a normal population:

$$L = \prod_{i=1}^{n} \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\tfrac{1}{2}\left(\frac{x_i-\mu}{\sigma}\right)^2\right) = \frac{1}{(2\pi\sigma^2)} n/2 \exp\left(-\frac{1}{2\sigma^2}\sum_{i=1}^{n}(x_i - u)^2\right) \qquad (5)$$

and therefore

$$\frac{L_{in}}{L_{on}} = \frac{\dfrac{1}{(2\pi\sigma^2)^{n/2}} \exp(-\dfrac{1}{2\sigma^2} \sum_{i=1}^{n} (x_i - \mu_1)^2)}{\dfrac{1}{(2\pi\sigma^2)^{n/2}} \exp(-\dfrac{1}{2\sigma^2} \sum_{i=1}^{n} (x_i - \mu_o)^2)} \tag{6}$$

which reduces to

$$\frac{L_{in}}{L_{on}} = \exp\left(\frac{\mu_1 - \mu_o}{\sigma^2} \sum_{i=1}^{n} x_i + \frac{n(\mu_o^2 - \mu_1^2)}{2\sigma^2}\right) \tag{7}$$

The decision rule for the sequential procedure will then reduce to:

1) Stop sampling and accept H_o if (7) < B

2) Stop sampling and accept H_1 if (7) > A (8)

3) Continue sampling if B < (7) < A

values of

$$B = \frac{\beta}{1-\alpha} \text{ and } A = \frac{1-\beta}{\alpha} \tag{9}$$

will result in a sequential test with the desired probabilities of error α and β.

Substituting (9) into (8), taking logarithms, and simplifying yields the following sequential procedure for a normal population with known variance:

1) Stop sampling and accept H_o if $\dfrac{\sigma^2}{\mu_1 - \mu_o} \log \dfrac{\beta}{1-\alpha} + \dfrac{n(\mu_1 + \mu_o)}{2} > \Sigma x_i$

2) Stop sampling and accept H_1 if $\dfrac{\sigma^2}{\mu_1 - \mu_o} \log \dfrac{1-\beta}{\alpha} + n(\dfrac{\mu_1 + \mu_o}{2})$

3) Continue sampling if

$$\frac{\sigma^2}{\mu_1 - \mu_o} \log \frac{\beta}{1-\alpha} + \frac{n(\mu_1 + \mu^d}{2} < \Sigma x_i < \frac{\sigma^2}{\mu_1 - \mu_o} \log \frac{1-\beta}{\alpha} + n(\frac{\mu_1 + \mu_o}{2})$$

where μ_o is as hypothesized in (3) and $\mu_1 = \mu_o + \delta\sigma$

Variance Unknown

If the variance of the normal population is unknown, the problem is considerably more difficult since the likelihood ratio (7) will

depend on the value of the unknown variance. If a reasonable approximation to the variance can be obtained, a sequential probability ratio test can be performed that will closely approximate the test for the variance known case. In most cases, this approximation will not be available. Use can then be made of the fact that a random variable formed as the ratio of a N(0,1) variable to the square root of a chi-square variable divided by its degrees of freedom follows a t distribution.

Under the assumption that the response variable, X_i, comes from a $N(\mu,\sigma^2)$ population, the sum of n observed responses will follow a $N(\mu,n\sigma^2)$ distribution and the statistic

$$Z = (\bar{X} - \mu)/\sigma/\sqrt{n} \tag{10}$$

will follow a N(0,1) distribution. A chi-square random variable with n degrees of freedom is the sum of the squares of n independent N(0,1) variables so the quantity

$$\sum_{i=1}^{n} ((X_i - \mu)/\sigma)^2 \tag{11}$$

will be distributed as chi-square with n degrees of freedom and the t-statistic proposed by Govindarajulu [2] can be formed.

The procedure of Baker [1] as modified by Hall [3] incorporates the required margin of difference, δ, in the formulation of the test statistic

$$r_n(S^2_{n_o}) = (\delta \sum_{i=1}^{n} (x_i - \delta/2))/S^2_{n_o} \qquad (n \geq n_o) \tag{12}$$

in the proposed two stage procedure. Baker develops the following as appropriate upper and lower bounds to the sampling region:

$$a_{n_o} = \tfrac{1}{2}(n_o-1)(\alpha^{-2/n_o-1} -1) \tag{13}$$

$$b_{n_o} = -\tfrac{1}{2}(n_o-1)(\beta^{-2/n_o-1} -1) \tag{14}$$

The sequential procedure for the variance unknown case then reduces to:

A. Observe the first n_o observations of the response variable, $x_1, x_2, \ldots, x_{n_o}$.

B. Compute the quantities:

$$\bar{x}_{n_o} = \sum_{i=1}^{n_o} x_i/n_o \tag{15}$$

and

$$S^2_{n_o} = \sum_{i=1}^{n_o} (x_i - \bar{x}_{n_o})^2/(n_o-1) \qquad (16)$$

C. For each observation $n \geq n_o$, after observing X_n:

1. Stop sampling and decide in favor of H_o if $r_n(S^2_{n_o}) < b_{n_o}$.
2. Stop sampling and decide in favor of H_1 if $r_n(S^2_{n_o}) > a_{n_o}$.
3. Continue sampling if $b_{n_o} < r_n(S^2_{n_o}) < a_{n_o}$

The modification of recomputing $S^2_{n_o}$, a_{n_o} and b_{n_o} after each observation may be easily incorporated into the procedure. This test would then be equivalent to the SPRT (σ^2 known) with wider boundaries to account for the fact that σ^2 is unknown but the boundaries would converge to the SPRT boundaries as n becomes large.

Solution Procedure

The proposed solution algorithm combines the sequential procedures just developed with a plan for systematically building a factorial experiment in order to obtain as much information as possible from the experiment in as few observations as possible. Use is made of screening experiments in building the full factorial in order to eliminate unnecessary control variables from future experimentation.

The first step, once the requirement to conduct operational testing is received, is to determine which variables can be expected to affect the response to be measured and how much they can be controlled. This will set the size of the full experiment. Determine the number of observations that can be made under homogeneous conditions and the generating relationship used to fractionate the full factorial. Once the first fraction is run, a sequential analysis is performed to determine if further experimentation is necessary. If it is, the second fraction, with all signs reversed, is run and the sequential procedure is repeated. In addition, analysis of the effects due to the various factors is performed to determine probable significance of effects. From this point on, each successive fraction is examined based on changing signs for appropriate factors in order to isolate those factors of interest. In case there are no factors or interactions of special interest, a heuristic approach would be to change the signs for the major factors proven to be significant to obtain as much information about them and their two factor interactions. Experimentation is terminated as soon as one of the sequential boundaries is crossed and a decision is made to accept one or another of the hypotheses. At this time, an analysis of variance can be performed to determine which effects are or are not significant.

The formalized algorithm is as follows:

1) Determine the variables of interest and the levels each are to be examined at.

2) Determine the number of observations that can be made under homogenous conditions.

3) Determine the generating relationship to fractionate the full factorial experiment so that the number of observations in a block, n_o, is less than or equal to the number determined in 2 above.

4) Determine required input data and parameters:

   a) Acceptable levels of type I and type II errors, α and β.

   b) Required difference margin, δ.

   c) Actual value of an estimate for variance of the response variable if possible.

   d) Hypotheses to be tested.

5) Pick one of the blocks at random and perform the experimentation.

6) If the value of the variance is unknown or if there is no reasonable estimate for the variance, go to 8. Otherwise continue.

7) Perform sequential analysis using the sequential probability ratio test since the variance is known. If the SPRT results in a decision to stop sampling, go to 14; otherwise, go to 9.

8) Perform sequential analysis using the sequential t test since the variance is unknown. If the sequential t test results in a decision to stop sampling, go to 14; otherwise, continue.

9) Perform the next block of experiments with all signs in the first block reversed. If the variance is known, go to 10. If the variance is not known, go to 11.

10) Perform sequential analysis using the SPRT. If the decision is to stop sampling, go to 14. If not, go to 12.

11) Perform sequential analysis using the sequential t test. If the decision is to stop sampling, go to 14. If not, continue.

12) Perform a screening analysis of the effects due to the main factors in order to determine relative significance of main factors and combinations of two-factor interactions.

13) Determine factors and interactions of interest and perform the next block of experiments found by switching the signs in the column for the factor of interest. If the variance is known, go to 10. If the variance is not known, go to 11.

14) Perform an ANOVA to determine the level of significance of all factors of interest. Eliminate non-significant factors from further testing by setting them at some common level.

15) If sequential analysis does not result in a decision in favor of one hypothesis or another, stop sampling and perform an ANOVA after one observation has been made at each treatment combination.

The proposed methodology will be illustrated in the next section by means of an example based on an actual operational test.

DEMONSTRATION OF THE APPROACH

This section will present an example of the methodology developed in the previous section. Hypothetical results from an Operational Test are presented and analyzed in the classical manner currently employed. Then the proposed methodology is applied to the same results with a reduction in the sample size required to gain the same information from the data.

BACKGROUND.

The Commander, U.S. Army Operational Test and Evaluation Agency (OTEA) has been given the requirement to conduct Operational testing to evaluate the overall effectiveness of the new Artillery Locating Radar, AN-TPQ-37, designed as a replacement for the system currently in use.

The test plan calls for testing several different performance aspects of the Artillery Locating Radar (ALR), one of which is its ability to detect hostile artillery fire. Since the radar cannot locate hostile artillery unless it first detects it, the most critical issue for this test is the percentage of hostile artillery rounds detected. The manufacturer has determined that five factors should influence the performance of the radar. They are the threat array employed by the enemy, the use of electronic counter measures (ECM) by the enemy, the rate of hostile fire, the range from the ALR to the enemy threat, and the sector the ALR is searching. All of these factors can be set at two levels except for the threat array. That can be set at one of four levels to represent the typical composition of enemy artillery units that the ALR is likely to be deployed against. Since four is a multiple of two, the threat array factor can be represented as two pseudo-factors each with two levels and the entire experiment can be represented as a 2^6 factorial experiment. The six factors and the levels of each factor are shown in Table 1.

Table 1. Factors in 2^6 Factorial Experiments.

Factor	Low Level	High Level
A - ECM	Not Employed	Employed
B - Rate of Fire	Slow	Fast
C - Range	Short $\leq$ 10,000 KM	Long $\geq$ 10,000 KM
D - Sector	Narrow ($\pm$ 15° of center	Wide (15-45° of center)
E - Threat Array	I	II
F - Threat Array	III	IV

Where THREAT ARRAY I = 1 enemy battery

II = 2 enemy batteries

III = 1 enemy battalion

IV = 2 enemy battalions

The Commander, OTEA, has stated that the ALR be tested by determining the percentage of hostile artillery rounds detected from firings taken at each of the 64 possible treatment combinations. The analysis method used will be Analysis of Variance (ANOVA) with all third order and higher interactions assumed to be negligible and pooled to form an estimate of the error. The standard for comparison is the current system which is detecting 50% of all hostile artillery rounds. The measure of effectiveness employed will be the percentage of rounds located. The principle purpose of the test will be to determine whether or not the mean percentage of rounds detected by the ALR exceeds the current system by some multiple of the standard deviation. It is assumed that the percentage of rounds detected comes from a normal distribution with unknown mean, μ, and variance, σ^2. Therefore, the testing will consist of a test of $H_0: \mu = \mu_0$ vs. $H_1: \mu = \mu_0 + \delta\sigma$, where δ is some positive constant.

Classical Methods

OTEA conducted test firings at all 64 treatment combinations and determined the percentage of rounds detected from each firing. Time limitations precluded any more than eight test firings per day so a 2^{6-3} resolution III design with I = ABD = ACE = BCF = BCDE = ACDF = ABEF = DEF as the generating relationship was used to fractionate the design and then the eight different blocks were fired in random order. The results, percentage of rounds detected, and the ANOVA for the entire experiment are shown in Tables 2 and 3. The results of the ANOVA indicate that only the factors relating to ECM, rate of fire, and sector of search are significant so OT II should be conducted using only those factors.

Proposed Methodology

Using the same data and restrictions as in the actual OT I, the following example will illustrate the proposed sequential procedure.

The first eight observations are obtained from the block generated by I = ABD = ACE = BCF = BCDE = ACDF = ABEF = DEF and consists of treatment combinations def (37), af (36) be (40), abd (87), cd (61), ace (34), bcf (46) and abcdef (89) where the values in parentheses represent the observed response for that treatment combination. Based on these observed responses, $\delta = 1$, $\alpha = .10$, and $\beta = .10$, the following computations are performed:

$$\bar{y} = 430/8 = 53.75 \tag{17}$$

$$S_8^2 = 3635.5/7 = 519.35 \tag{18}$$

$$A_8 = \tfrac{1}{2}(7)(.1^{-2/7} - 1) = 3.26 \tag{19}$$

$$B_8 = -\tfrac{1}{2}(7)(.1^{-2/7} - 1) = -3.26 \tag{20}$$

$$r_8(S_8^2) = \delta(\Sigma(x_i - \delta/2))/S_8^2 = 426/519.35 = .82 \tag{21}$$

Since $B_8 < r_8(S_8^2) < A_8$, the decision is made to continue sampling.

The alias structure for this 2^{6-3} resolution III design is shown in Table 4. Assuming that all third order and higher interactions are negligible, each major factor is aliased with two two-factor interactions.

Table 2. Data from the Full 2^6 Factorial Experiment

(1)	24	e	10	f	18	ef	18
a	38	ae	46	af	36	aef	34
b	33	be	40	bf	31	bef	32
ab	56	abe	74	abf	74	abef	69
c	15	ce	13	cf	11	cef	10
ac	42	ace	34	acf	41	acef	43
bc	34	bce	30	bcf	46	bcef	39
abc	69	abce	72	abcf	47	abcef	44
d	57	de	53	df	45	def	37
ad	66	ade	75	adf	66	adef	60
bd	79	bde	70	bdf	56	bdef	67
abd	67	abde	83	abdf	88	abdef	86
cd	61	cde	49	cdf	47	cdef	48
acd	78	acde	72	acdf	67	acdef	75
bcd	67	bcde	56	bcdf	65	bcdef	70
abcd	95	abcde	89	abcdf	82	abcdef	89

Table 3. Analysis of Variance Table for the Entire Data Set

ANOVA

Source	SS	DF	MS	F_o
ECM	8695.56	1	8695.56	180.5**
Rate of Fire	6201.56	1	6201.56	128.7**
Range	1.00	1	1.00	.02
Sector	14460.06	1	14460.06	300.2**
Threat Array*	286.375	3	95.46	1.98
Error	2697.445	56	48.16	
Total	23342.	63		

*$SS_{\text{Threat Array}} = SS_E + SS_F + SS_{EF}$

**Significant at 1% level.

Table 4. Alias Structure for 2^{6-3}_{III} Design

Factor	ALIASES						
I	ABD	ACE	BCF	BCDE	ACDF	ABEF	DEF
A	BD	CE	ABCF	ABCDE	CDF	BEF	ADEF
B	AD	ABCE	CF	CDE	ABCDF	AEF	BDEF
C	ABCD	AE	BF	BDE	ADF	ABCEF	CDEF
D	AB	ACDE	BCDF	BCE	ACF	ABDEF	EF
E	ABDE	AC	BCEF	BCD	ACDEF	ABF	DF
F	ABDF	ACEF	BC	BCDEF	ACD	ABE	DE
AF	BDF	CEF	ABC	ABCDEF	CD	BE	ADE

Table 5. Screening Results of Blocks 1 and 2.

$\ell_A = A + BD + CE = 62/3 = 20.67$ $\qquad \ell'_A = -A + BD + CE = -44.67$

$\ell_B = B + AD + CF = 31.33$ $\qquad \ell'_B = -B + AD + CF = -24.67$

$\ell_C = C + AE + BF = 10.00$ $\qquad \ell'_C = -C + AE + BF = 7.33$

$\ell_D = D + AB + EF = 39.33$ $\qquad \ell'_D = -D + AB + EF = -27.33$

$\ell_E = E + AC + DF = -10.00$ $\qquad \ell'_E = -E + AC + DF = 2.00$

$\ell_F = F + BC + DE = -4.67$ $\qquad \ell'_F = -F + BC + DE = 7.33$

$\ell_{CD} = CD + BE + AF = 4.00$ $\qquad \ell'_{CD} = CD + BE + AF = 18.67$

$\frac{1}{2}(\ell_i + \ell'_i)$	$\frac{1}{2}(\ell_i - \ell'_i$
BD + CE = 12.00	A = 32.67
AD + CF = 3.33	B = 28.00
AE + BF = 8.67	C = 1.33
AB + EF = 6.00	D = 33.33
AC + DF = -4.00	E = -6.00
BC + DE = 1.33	F = -6.00

In order to separate the main effects from their aliased two-factor interactions, the next block run will be the same as the first but with all signs reversed. The defining relationship for this block will then be I = -ABD = -ACE = -BCF = BCDE = ACDF = ABDF = -DEF. The block consists of the following treatment combinations and their observed responses: abc (69), bcde (56), acdf (67), cef (10), abef (69), bdf (56, ade (75), and (1)(24). Sequential calculations result in the following:

$$\overline{y} = 856/16 = 53.5 \tag{22}$$

$$S^2_{16} = 502.4 \tag{23}$$

$$A_{16} = 2.695 \quad , \quad B_{16} = -2.695 \tag{24}$$

$$r_{16}(S^2_{16}) = 848/502.4 = 1.69 \tag{25}$$

Since $B_{16} < r_{16}(S^2_{16}) < A_{16}$, the decision is made to continue sampling. Before the next block is run, however, an analysis of the results obtained so far is performed. The results are shown in Table 5. Based on the relative magnitude of the effects, it would appear that factors A, B, and D were significant while factors C, E, and F were not. Since the largest interaction term is due to BD and CE, it is also possible that the BD interaction is significant. Since the decision has already been made to continue sampling, the next block run will be the same as the first block except that all of the signs in the column for factor B will be reversed. This will isolate factor B and all of its two factor interactions and will provide a better estimate of whether or not the BD interaction is significant.

The third block then consists of the following treatment combinations and their observed responses: bdef (67), abf (74), e (10), ad (66), bcd (67), abce (72), cf (11), acdef (75). The sequential calculations result in the following:

$$\overline{y} = 1298/24 = 54.08 \tag{26}$$

$$S^2_{24} = 563.99 \tag{27}$$

$$A_{24} = 2.55 \quad B_{24} = 2.55 \tag{28}$$

$$r_{24}(S^2_{24}) = 1286/563.99 = 2.28 \tag{29}$$

Since $B_{24} < r_{24}(S^2_{24}) < A_{24}$, the decision is made to continue sampling. An analysis of the results of the data from the third block indicates that once again, factors A, B, and D appear to be significant while the BD interaction is still in doubt. After the second block, the effect in question was due to the BD and CE interactions so it is possible that this was due to the CE rather than the BD interaction. Since the decision has been made to continue sampling, the next block run will change the signs in the column for factor c to isolate factor c and its two factor interactions. This block contains the following treatment combinations and observed responses: cdef (48), acf (41), bce (30), abcd (95), d (57), ae (46), bf (31), and abdef (86). The sequential calculations result in the following.

$$\bar{y} = 1732/32 = 54.125 \tag{30}$$

$$S_{32}^2 = 550.31 \tag{31}$$

$$A_{32} = 2.48 \quad , \quad B_{32} = -2.48 \tag{32}$$

$$r_{32}(S_{32}^2) = 1716/550.31 = 3.12 \tag{33}$$

Since $r_{32}(S_{32}^2) > A_{32}$, the decision is made to stop sampling and accept $H_1: u = u_o + \delta\sigma = 50 + \sigma$. This means that the ALR has performed better to date than the current system. The analysis of the data from the fourth block indicates that once again factors A, B, and D appear to be significant while the CE interaction does not. Since the decision has been made to stop sampling, the recommendation made at this point would be to perform OT II using only the factors for ECM, rate of fire, and sector. The other factors would be set at some acceptable standard level and left there.

CONCLUSION

This research accomplished three objectives:

A. An approach to systematically building a factorial experiment through the use of screening experiments was demonstrated. This allows the experimenter to obtain as much information as possible from a fixed set of resources.

B. A method of sequentially analyzing the data from a fractionated factorial experiment was demonstrated. This allows the experimenter to obtain a fixed amount of information from a reduced set of resources.

C. The proposed methodology combined the above two methods to systematically build a factorial experiment while conducting a sequential analysis of the data at the end of each block of the factorial experiment. This allows the experimenter to gain the maximum amount of information from a minimum amount of resources.

Although the proposed approach was only demonstrated against the data from one operational test, it resulted in a substantial reduction in the number of experimental trials required to obtain the same amount of information. Where the classical methods currently employed would require that the full 64 experimental trials be performed, the proposed approach required only 32 observations to reach the same conclusions.

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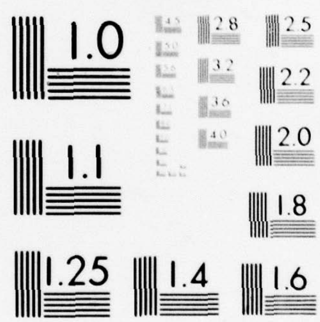

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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TITLE: Aspects of Designing a Target Detection Experiment

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ABSTRACT: In planning a target detection experiment, information was drawn from a previously conducted experiment of a similar nature. This information took the form of a reanalysis which revealed the following. The probability of detection in the time interval $(t, t + \Delta t)$, given non-detection in (o, t), is not constant, or, put simply, the present is not independent of the past. Additionally, regression analysis can provide adequate predictions of detection times through target scene variables. These results are used as input in proposed experiment.

Aspects of Designing a Target Detection Experiment
Dr. William S. Mallios
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1. Summary. Objectives of the Army Small Arms Requirement Study No. 2 (ASARS II) were to obtain data to assist in defining the principal determinant variables in the detection of human targets in tactical environments and to obtain data to assist in confirming the probability distribution of detection times. Due to similarities between these objectives and those of the previously conducted CDEC Experiment 31.1, data from 31.1 were reanalyzed. Results of this analysis were (1) that the probability distribution of detection times, conditional on principal determinant variables, is appropriately given by the log normal as opposed to the Weibull distribution; (2) that within the time frame of detection, the present is not independent of the past; and (3) that the expected detection time can be adequately predicted in terms of principal determinant variables (specifically, contrast, range, and scene complexity) through regression analysis. These results formed an input to the design of ASARS II and provided an alternative modeling approach for predicting detection times conditional on principal determinant variables.

2. Probability Distributions for Detection Times. In document (1), the probability distribution of detection times is derived under the assumption that the probability of detection in the time interval $(t, t + \Delta t)$ is independent of the detection probability in the interval (o, t). This assumption sacrifices realism for the mathematical simplicity of the exponential density. Competing densities which offer more realism (and involve slightly more mathematical complexity) are the Weibull and log normal densities. With the understanding that t is an observed detection time for the Weibull and the logarithm of an observed detection time for the log normal, we have

Normal density: $f_N(t) = f(t: \mu,\sigma^2) = (2\Pi\sigma^2)^{1/2}\left|\exp -(t - \mu)^2/2\sigma^2\right|$

Weibull density: $f_W(t) = f(t; \alpha,\beta,\gamma) = \beta(t - \gamma)^{\beta-1}\alpha^{-1} \exp\left| -(t - \gamma)^{\beta}/\alpha\right|$,
where (μ, σ^2) and

$$\left|\gamma + \alpha^{1/\beta}\,\Gamma(1 + 1/\beta),\ \alpha^{2/\beta}\left|\Gamma(1 + 2/\beta) - \Gamma^2(1 + 1/\beta)\right|\right|$$

are, respectively, the first two moments of the normal and Weibull distributions. Shapes of these distributions are shown in Figure 1 where it is noted that the Weibull reduces to the exponential density for $\beta = 1$. Detection rate is given by

$$\lambda(t, t + \Delta t) = \int_t^{t+\Delta t} f(t)dt \Big/ \int_t^{\infty} f(t)dt\ ,$$

the probability of detection in $(t, t + \Delta t)$, given non-detection in (o, t). For the normal distribution $\lambda(t, t + \Delta t)$ cannot be simply expressed, while for the Weibull

$$\lambda_W(t, t + \Delta t) = 1 - \exp\left\{\frac{t^{\beta}}{\alpha} - \frac{(t + \Delta t)^{\beta}}{\alpha}\right\}$$

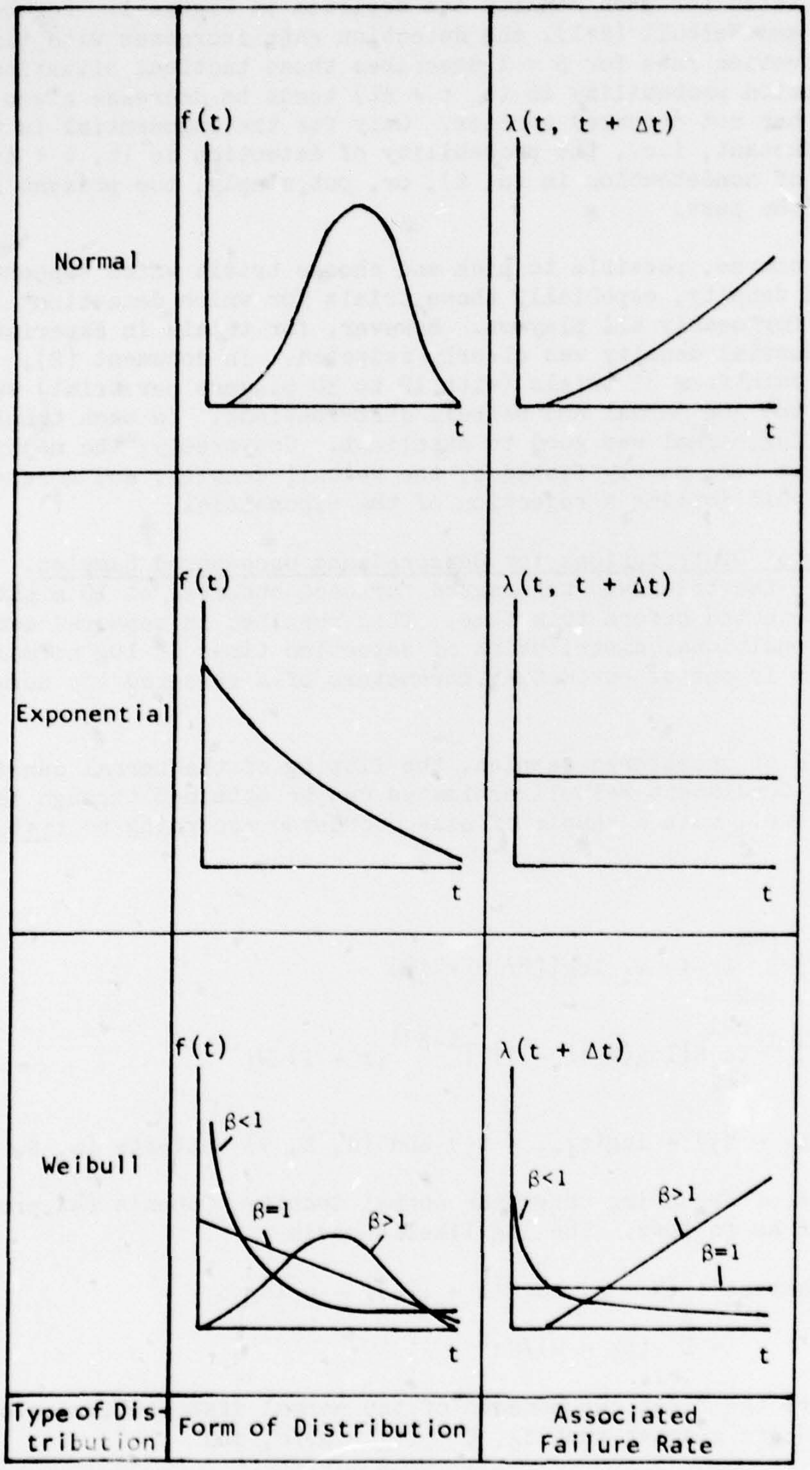

Figure 1. Types of Probability Distributions Encountered in Target Detection and Their Associated Detection Rates

Detection rates for each density are depicted in Figure 1. For both the log normal and Weibull ($\beta>1$), the detection rate increases with time. The Weibull detection rate for $\beta < 1$ describes those tactical situations where the detection probability in $(t, t + \Delta t)$ tends to decrease given that detection has not occurred earlier. Only for the exponential is the failure rate constant, i.e., the probability of detection in $(t, t + \Delta t)$ is independent of nondetection in (o, t), or, put simply, the present is independent of the past.

It is, of course, possible to pick and choose trials which support the exponential density, especially those trials for which detection occurs quickly for nearly all players. However, for trials in Experiment 31.1, the exponential density was clearly rejected. In document (2), detection time data from 33 trials (with 12 to 30 players per trial) were fitted to both the log normal and Weibull distributions. In each trial, the fit of the log normal was good to excellent. Conversely, the majority of the trials were poorly fitted by the Weibull density; and a rejection of the Weibull implies a rejection of the exponential.

3. <u>The Fitting of Distributions for Censored and Uncensored Samples</u>. In Experiment 31.1, the trial was terminated for each observer at 10 minutes if he had not detected before this time. This resulted in censored samples. If the conditional distribution of detection times is log normal, then the problem is one of estimating parameters of a censored log normal distribution.

In the case of uncensored samples, the fitting of the normal density is well known. Consistent Weibull estimates can be obtained through Kao's procedure (3); i.e., with a sample of size n ordered according to $t_1 \leq t_2 \leq \cdots \leq t_n$,

$$\hat{\gamma} = t_1$$

$$\hat{\beta} = (n - 2)/\sum_{i=2}^{r-1} (r-i)\, W_i \log[(r/\, r - i])$$

$$\hat{\alpha} = (n - 2)^{-1} \sum_{i=2}^{r-1} \hat{\beta}[\log(r/[r - i])]^{1-\hat{\beta}^{-1}} (r - i)\, W_i$$

where $W_i = \log(t_i - t_1) - \log(t_{i-1} - t_1)$ and $(\hat{\alpha}, \hat{\beta}, \hat{\gamma})$ estimate (α, β, γ).

In the case of censoring under the normal density, Cohen's (4) procedure is utilized as follows. The log likelihood is

$$\log L = \text{constant} + (N - n) \log [1 - I(\xi)] - n \log \sigma - \sum_{i=1}^{n} (t_i - \mu)/2\sigma^2$$

where (μ, σ^2) are the first two moments of the normal distribution, n observations out of N are greater than t_o, $\xi = (t_o - \mu)/\sigma$, and

$$I(\xi) = \int_{\xi}^{\infty} \phi(u)du, \quad \phi(u) = (2\Pi)^{-\frac{1}{2}} \exp(-u^2/2).$$

Applying maximum likelihood estimation and taking partials of log L with respect to μ and σ leads to the following equations:

$$\hat{\xi} = (\hat{\sigma}^2 - V_2)/V_1\hat{\sigma}$$

$$\hat{\mu} = t_o - (\sigma^2 - V_2)/V_1$$

where $V_r = \sum_{i=1}^{m} (t_i - t_o)^{r/m}$, and $(\hat{\xi}, \hat{\mu}, \hat{\sigma})$ denotes the estimate of (ξ, μ, σ).

4. Regression Analysis in the Prediction of Detection Times. It is stated in document (1) that through regression analysis, the variability in detection times was not adequately explained through target scene variables in Experiment 31.1. How those authors arrived at such a conclusion is left to the imagination since regression analysis does indeed explain target detection times in Experiment 31.1. Our finding allows for considerably more flexibility and power in design and prediction since one can utilize conditional distributions (conditional on predictors in the regression equation) rather than having to resort to marginal distributions (see (2)).

In the regression system, the dependent variables are expected detection time for any given trial and percentage of players detecting for any given trial. On a per trial basis these variables are estimated by

$$Y_{1j} = \sum_{i=1}^{n_j} \log Y_{ij}/n_j = \sum_{i=1}^{n_j} t_{ij}/n_j, \; Y_{2j} = n_j/N_j$$

where T = Number of trials, $Y_{ij} \le 10$ minutes is the detection time for the i-th observer (player) in the j-th trial, 10 minutes is the truncation point, and n_j is the number of players out of N_j detecting on the j-th trial. The response Y_{ij} is transformed to log Y_{ij} under the assumption of a log normal distribution of detection times conditional on principal determinant variables. The response Y_{2j} is to be predicted so as to allow for the conditional prediction of log normal parameters in the presence of censoring.

The nine different targets in 31.1, covering combinations of men and vehicles (both moving and stationary), are quantified in terms of the five independent variables C_L, A_o, ΣA_o, W, and D, as follows:

Target	Class(C_L)	A_o	ΣA_o	W	D
A	4	.5	1.5	12	.25
B	1	1.0	9.0	35	.26
C	3	15.0	20.0	20	.07
D	3	10.0	30.0	20	.15
E	2	1.0	8.0	20	.40
F	2	1.0	20.0	150	.13
G	1	15.0	30.0	20	.10
H	1	15.0	30.0	20	.10
I	1	5.0	10.0	10	.20

where A_o = Area of individual elements in square meters (see (5)), ΣA_o = Sum of area of individual elements, W = Width encompassed by target in meters, and $D = \Sigma A_o/WA_o$ = Approximate density of target type. The values of 1 through 4 given to the variable C_L is an attempt to distinguish, approximately, between different speeds and sounds of the target types in terms of one variable. For example, target type E is a squad of eight men moving toward the observers in a modified column. Each of the men is about one square meter in area ($A_o = 1$); there are 8 men ($\Sigma A_o = 8$), and space spanned by these men is 20 meters. Thus, an approximate measure of the density of this target type is $D = \Sigma A_o/WA_o = .40$. In addition to C_L, A_o, ΣA_o, W, and D, other independent variables are:

P = 0 when the players are artillery observers,
  = 1 when the players are mortar observers,
R = Target range in kilometers,
B_h is the luminance of the horizon sky just above the target-observer line,
B_s is a photometric measure of scene brightness for each target presentation,
C_o = .20 when target scene has a tree background,
  = .40 when target scene has a grass background,
  = .30 when target scene has a tree and grass background,
  = .50 for each target on hilltop with grass backdrop,
  = .30 for target on hilltop with tree backdrop.

The above values of C_o were given by Richardson (5) where Co is intended to approximate

$$(\text{inherent contrast}) = 1 - \frac{(\text{target luminance at range } R - o)}{(\text{background luminance at range } R = o)}$$

which was measured unsuccessfully during 31.1 experimentation.

Apparent contrast is then approximated by

$$C_r = \left|1 + (B_n/B_s)(\exp\left|-\beta R\right|-1)\right|C_o = FC_o$$

where β, the atmospheric attenuation coefficient, is taken as .02.

Setting $Y_1 = f(C_L, A_o, \Sigma A_o, W, D, P, R, B_n/B_s, C_r, F, C_o)$, and expanding f in a Taylor series to include all first order and selected higher order terms, we then scan all these predictors through stepwise least squares estimation (6), the results of which are given in Table 1. In predicting Y_1, C_o^2 is the most dominant variable, in the sense that C_o^2 accounts for 47.36% of the variability in the Y_{1j}. The variable C_oDR is the second most dominant variable in that, together, C_o^2 and C_oDR account for 60.54% of the variability in the Y_{1j}. The reason C_o^2 is removed in step 9 is that, by that step, the effect of C_o has been spread over a number of variables, namely those appearing in steps 2, 3, and 7.

The results in Table 2 clearly show that the expected detection time can be reliably predicted in terms of R, C_o, B_n/B_s and supporting variables within the realm of the data. For extrapolations, further experimentation is necessary to extend the response surface which, of course, is the purpose of ASARS II. The prediction equation for Y, plus analysis results for Y_2 are given in (2).

Step	Independent Variable Entered	Independent Variable Removed	Proportional Reduction in Variability for Log Detection Time
1	C_c^2		.4736
2	C_oDR		.6054
3	C_rP		.6485
4	C_LB_h/B_s		.6827
5	FA_o		.6975
6	D		.7258
7	C_c		.7383
8	DR		.7549
9		C_o^2	.7549
10	PDFR		.7606
11	PC_rD		.7743
12	$\Sigma A_oB_h/B_\Delta$		.7790
13	A_oB_h/B_Δ		.7845
14	$C_r\Sigma A_o$		.7957

Table 1. Results of stepwise least squares estimation: an ordering of those independent variables found most dominant in reducing proportional variability in the Y_{1j}.

5. <u>Application of 31.1 Analysis to ASARS II</u>. Results of the 31.1 reanalysis which will likely carry over to ASARS II are that detection times are log normally distributed, that detection times can be adequately predicted through principal dominant variables in terms of regression analysis, that principal determinant variables are range, inherent and apparent contrast, and target characteristics, and that inherent contrast can be adequately approximated through measures of scene complexity if attempts to measure inherent contrast are not successful.

All of the prediction variables are easily controlled except for apparent and inherent contrast. If necessary, however, scene complexity measure can adquately replace inherent contrast (at least regarding prediction) and can be controlled. Since attempts at controlling uncontrolled variables might result in the experimental technique affecting the outcome of the experiment, B_h/B_s and actual measures of contrast are left as variables to be measured in each trial. However, a sufficient number of trials are planned for each treatment combination to allow for a rather broad spectrum of B_h/B_s and contrast values within treatment combinations. This allowance is made possible by having established the applicability of regression analysis. For, the fact that a response surface will adequately fit the resulting data means that the effect of B_h/B_s can be estimated even if a broad spectrum of these values does not occur for each treatment combination. Moreover, if it is possible to successfully measure inherent contrast, these values can be compared with the approximate measures of inherent contrast, so as to establish which has a greater predictive influence on detection time.

6. <u>Estimating Parameters of the Conditional Log Normal Distribution Through Regression</u>. The prediction for Y_1 is written as $\hat{Y}_1 = C_o + \Sigma_{i=1}^{p} C_i\gamma_i$, where the C's are estimated coefficients and the γ_i are independent variables. Conditional on $\underline{\gamma} = \underline{\gamma}^* = (\gamma_1^*, \cdots, \gamma_p^*)'$, Y_1 is predicted by

$\hat{Y}_1^*$. If interest is on the average of the log detection times of N_j observers for a single trial, then variance $\hat{Y}_1^* = (1 + T^{-1} + \underline{y}^{*\prime}(x'x)^{-1}\underline{y}^*)\hat{\sigma}^2$, where X is the T x p matrix of values of the γ_i used in determining the C's, and $\hat{\sigma}^2$ is the estimated variability about the regression surface; see (7). The prediction $\hat{Y}_1^*$ thus estimates the expectation of the conditional log normal density (assuming no censoring) while N_j var $\hat{Y}_1^*$ estimates the variance on a per observer basis. When censoring is imposed, the prediction model for Y_2 must be utilized along with the formulas in Section 3; see (2).

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ABSTRACT

TITLE: Baselines Where No Baseline Exists

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ORGANIZATION: Test Design Division, USAOTEA

ABSTRACT: The Army of 1980's will have a shortened materiel acquisition cycle for weapon systems which will be more costly, sophisticated, and unique than current weapon systems. Testing, in particular, operational testing, will become an increasingly expensive proposition because of the necessity to provide more answers in a shorter timeframe with systems whose testing becomes increasingly difficult. However, decision makers will still require sufficient information about system capabilities and constraints in order to make sound procurement decisions.

One of the critical issues for the testing community is the availability of a baseline against which each system will be tested. By baseline, we mean the standard of comparison. Baselines generally are:

criteria - which are set by the user and represent the minimum acceptable values of a system's performance parameters
current production systems - which provide a means of physical comparison
models - which provide a comparison between forecasted capabilities and observed capabilities

In the 1980's, test and evaluation of unique and new systems in the materiel acquisition process will utilize models less applicable than those today, and current systems less equivalent in operational capability. A solution for future testing is criteria; quantifiable, realistic and testable criteria which relate directly to the decision at the level where the decision is required.

This paper addresses the impact of criteria on operational testing. Several aspects of criteria are examined in terms of test design, execution, and evaluation.

BASELINES WHERE NO BASELINE EXISTS

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In recent years, the procurement of military systems has become progressively more expensive. Rapidly advancing technology, inflation, and the world political situation will force this trend to continue in the future. The Department of the Army has taken a number of steps to reduce the problems of maintaining a viable military capability within political and budgetary constraints. While actions such as manpower reductions are highly publicized, other less publicized actions such as the elimination, in most cases, of the final deployment operational test, OT III (in favor of follow on evaluations and operational climatic tests, as required) have significant impact on the material acquisition process. Systems which are more costly, more sophisticated, and more unique than current systems are being forced into a shortened acquisition cycle. This shortening means that operational testing must provide more answers in a shorter period of time with systems whose testing becomes increasingly difficult. However, decision makers will still require sufficient information about system capabilities and constraints to make procurement decisions.

One of the critical issues in the development of this information by the testing community is the availability of a baseline to use as a standard of comparison. Typical baselines are:

- Predetermined values which are set by the user to represent the minimum acceptable values of a system's performance parameters.

- Current production systems which permit a physical comparison.

- Models which provide a comparison between forecasted capabilities and observed capabilities by representing the tested system in its operational environment with mathematics and/or a slice of the real world.

The current major and selected category 1 nonmajor systems assigned to the Army's Operational Test and Evaluation Agency (OTEA) for testing show that baseline problems already exist (see Table 1). Of 37 systems, over one third are either unique with no comparable system in the inventory or represent such a marked advancement over current systems that a comparison is untenable. Fewer unique systems are found among lower cost procurement programs.

TABLE 1. SYSTEM UNIQUENESS

Type system	Total number of systems	Unique	% of total
Major and Category 1	37	14	37.8
Category 2	61	11	18.0
Category 3	57	7	12.3
Category 4	327	25	7.6
Total	482	57	11.8

The "Big Five" (i.e., XM1 tank, Black Hawk helicopter, advanced attack helicopter, infantry fighting vehicle, and PATRIOT anti-aircraft missile) have baseline problems in testing for system performance, human factors, and reliability, availability, and maintainability (RAM)/logistics. Each represents unique improvements when compared to current system capabilities and/or substantial changes in doctrine.

Obvious questions are "Where does unique begin?" and "When is an existing system no longer a realistic baseline?" Answers to these questions are neither obvious nor readily determined.

The basic impact on testing with a baseline is in terms of adequacy, quality, and credibility. The use of baselines is directly related to the development of test criteria. These criteria are an expression of the operational level of performance required of a system to demonstrate operational effectiveness for a given function during each operational test. A criterion is generally comprised of the following elements:

o The function addressed - a system capability such as hitting performance.

o The basis for comparison - a new system versus replaced system, the unit with the new system versus a unit without the new system or a new system versus a predetermined standard.

o The performance required - test results required such as a probability of hit of 0.95.

o The conditions associated with the test criteria - conditions such as day and night.

• The confidence level - the degree of risk acceptable to a decision maker as related to the performance required such as a .95 probability of hit at the 90% confidence level.

The impact of criteria is felt throughout the operational testing process. Test planning, execution, and evaluation cannot be effectively conducted without adequate criteria which define the users' requirements.

The user and the tester cooperatively develop criteria statements; however, the user must fill in the blanks with standards of performance and confidence levels. These criteria may be developed by comparing the new system with old (but similar) systems, enemy capabilities, user requirements, and expert judgement.

Good test design, execution, and evaluation is particularly dependent on criteria for the development of performance, human factors, and RAM/logistics parameters. System performance is generally the easiest to address. Nevertheless, some systems such as command, control, and communications (C3) systems and electronic warfare (EW) systems do not have easily defined relevant measures of performance nor do they presently have sufficient criteria. Many C3 systems and EW systems (currently of particular interest) are often one of a kind with no comparable deployed systems.

System performance generally involves response variables which are historically standard and established by system type. Figure 1 provides an example.

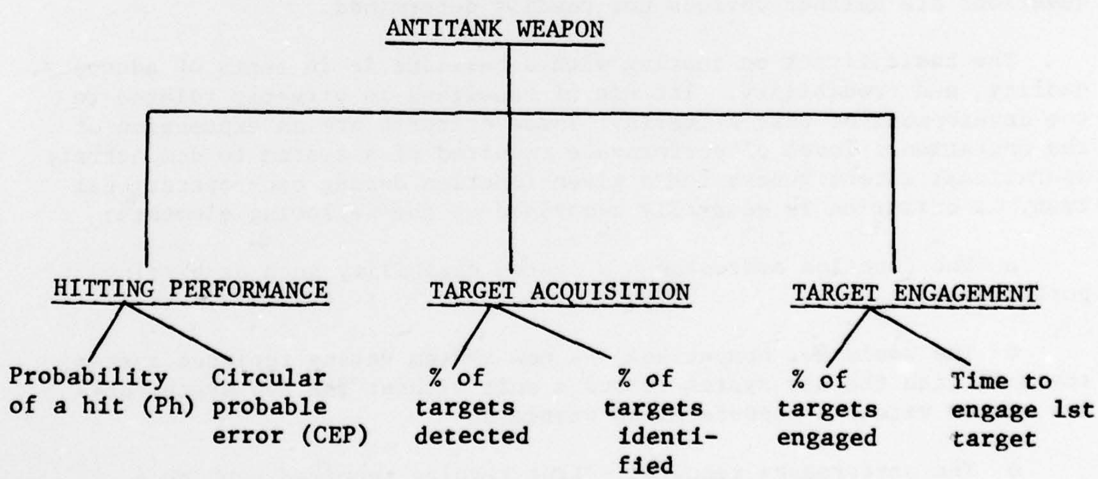

Figure 1. System performance

Similar breakdowns are available or can be easily constructed for most systems. While the means of system performance may be unique, the measures by which they are evaluated are usually not unique. For example, the Copperhead (Cannon Launched Guided Projectile) system includes the first "smart" artillery round which functions similar to the "smart" bombs used successfully by the Air Force in Vietnam. The round has a terminal guidance system which homes in on a laser illuminated point target such as an enemy tank. The Copperhead has the unique capability of neutralizing point targets at distances where previously artillery could only employ area fire. In Operational Test II, hitting performance will be evaluated with both area fire measures of effectiveness and those measures associated with flat trajectory weapons. Hence, the common measures for point target engagements will be used in assessing the unique "point target" capability of the Copperhead.

Operational tests are also strongly influenced by the conditions over which a system is to be tested, the amount of variability allowed, and the number of new systems available for test. Sometimes forgotten, however, are the human factors.

Typicality of the player personnel employed during the test and training problems invariably raise their ugly heads. Typicality of soldiers, as a problem, is still a matter of the user and tester jointly defining typicality and the player selection process.

The relative level of training attained by players in operational tests is also a problem from the point of view of establishing a set of pertinent criteria. The type of baseline is of particular importance. Fewer problems arise in the comparison of a candidate system with the current production system than in a comparison using predetermined values as models. While some controversy may be apparent in the use of a crossover (i.e., training and using all test personnel on both systems rather than dedicated crews on each system) design in training and testing, such a design permits efficient use of limited personnel resources, avoids problems associated with randomization of matching procedures, allows for meaningful crew position cross system comparisons, and provides enhanced user preference data.

If a candidate system has no comparable deployed system, human factors revert to basic components, skills, and capabilities. Even unique systems generally have subsystems and/or components which are not unique. For example, a new C3 system which is unique overall may have a terminal or a man-machine interface of standard design. The testing of a system in its totality sometimes is necessary for complete assessment of its utility and to gain a feeling of subjective confidence; however, resources, security, or just common sense may dictate otherwise.

RAM/logistical problems during test planning revolve around equating the system's operational mode summary and mission profile(s) to RAM/logistics measures. As with system performance in general, the question is "What is the standard required/what criteria should apply? RAM measures such as mean time between failure, mean time to repair, system reliability and operational availability are in common use and are easily stated. While RAM is an integral part of logistics, logistics measures, in general, are not as well-developed for operational testing. The key is the logistics support concept (a responsibility of the US Army Training and Doctrines Command in conjunction with the US Army Development and Readiness Command). The question usually is, "Is the logistics support adequate?" This is too general. Logistics support should be subdivided into:

- Logistics concept.
- Logistics support materiel.
- Logistics support personnel.
- Hardware/system characteristics.

Criteria associated with the abovementioned areas remain primarily subjective in nature, but a substantial relationship between RAM and logistics should be considered in each logistics evaluation. Criteria will also vary with changes in the size of the slice of the force being portrayed and test length. This includes the actual number of units, the level or portrayal, and the degree of detail.

RAM criteria, in particular the minimum acceptable value (MAV) for mean time between failures (MTBF), frequently dictate the length of test required for a valid assessment. The process of sizing a test and developing a plan of analysis is directly related to the type of baseline and the measure of performance.

Product improvements, from the sizing viewpoint, have considerable advantages in resource needs. Here, it may be possible to use a paired comparison. While the relationships shown in Figure 2 are by no means original, the relative change in sample size may not be as apparent. Note that the difference between paired and unpaired as shown in Table 2 is an order of magnitude. Single-sided tests require approximately 20% fewer units than double-sided tests. The single-sided versus double-sided comparison is of particular importance. A side-by-side test of two candidates forces a double-sided test, while a product improvement of low risk could perhaps be conducted single-sided.

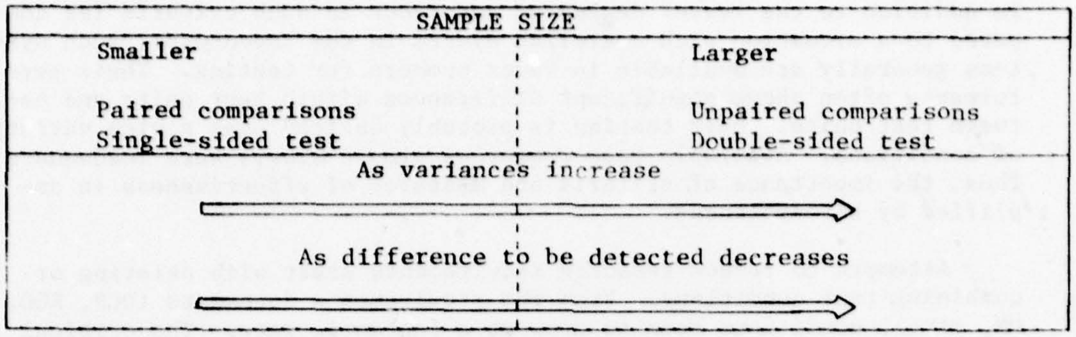

Figure 2. Sample sizing factors

TABLE 2. SAMPLE SIZE EXAMPLE

Unpaired		Paired	
Double-sided	Single-sided	Double-sided	Single-sided
491	414	38	32

D = .75 δ = .75 σ = 1.00

A new system with no physical baseline system is the worst case situation. Here, the test criteria are predetermined performance values which may be related to:

- Performance of a military unit with the system versus the unit without the system.

- Subsystem performance.

or less preferred

- The system specification.

In addition to the lesser degree of assurance in such criteria (as compared to a situation with a similar system in the inventory), such systems generally are available in fewer numbers for testing. Their performance often shows significant differences within test units and between test units. Unit testing is probably desired over a wide variety of conditions. Available test resources almost always seem inadequate. Thus, the importance of criteria and measures of effectiveness is amplified by circumstances.

Attempts to reduce resource requirements start with deleting or combining test conditions. From the requirements documents (DCP, ROC, MN, etc.), conditions seem to grow at a fantastic rate. The critical conditions set by the user are required. All others, no matter how sacred someone may think them, are possible candidates for elimination. One of the basic questions that needs to be asked is if meaningful data can be collected. Problems often preclude or constrain examination of the tested system, including:

- Confounding.
- Inadequate instrumentation.
- System limitations.
- Test conditions.

The amount of error in instrumentation alone may exceed the criterion for a particular measure of effectiveness.

The selection of a measure is critical. Miles per gallon is a perfectly good measure for the fuel consumption of a land vehicle, yet it is unacceptable for an aircraft. Pounds of fuel per hour, while appropriate for an aircraft, is ludicrous for a tank.

The level of a measure as an idea relates to the story of: how for the sake of a horseshoe nail, a horseshoe, horse, courier, et cetera, a war was lost. Does one measure the quality of performance of a horseshoe nail by the number of wars won and lost? The best measure of a horseshoe nail is how well it holds the shoe to the horse. On the other hand, one does not measure the effectiveness of an Army in terms of the numbers of lost horseshoe nails. A company commander thinks in terms of the added firepower or accuracy he has available, while the Corps Support Commander thinks in terms of tonnages and volumes to support that capability.

To be properly addressed, an issue may need two or more criteria. For example, a communications system may require one criterion to address the user's needs and one to address the supporting unit's requirements.

Testing is more than a statistical, experimental design. It is the process of relating testing requirements to resources during a specified timeframe. Thus, during test planning and preparation, criteria provide the foundation and framework for the conduct of the test.

During the conduct of operational testing, criteria maintain their importance. Observance of the relationship of actual system performance to a criterion during a test assists the test directorate in identifying problems (areas in which test resources should be closely monitored). The tester (while maintaining an adequate test) seeks to avoid unnecessary costs. Reduction in such expenditures are possible when criteria are either met or "failed" at a specified level of confidence. RAM is one area in which criteria strongly influences test length. Occurrence of system failures in excess of criterion is an indicator of system performance and may be a sufficient reason for termination of a test. However, the converse might arise. Limited failures or misses in X number of rounds fired may provide a basis for not firing the total number of rounds allocated for the test. A round may be more accurate than originally planned, or just show less variance in overall performance. The use of criteria as a management tool may:

- Save resources.
- Permit a more equitable examination of a systems capabilities.
- Reduce hazards to personnel.
- Permit critical program decision early in the acquisition process.

Of course the time to consider criteria for test management is early in the advance stages of system planning and development and not just prior to testing.

The question, "How does the user establish criteria?", is frequently asked. The response is generally in terms of a reference to current publications such as AR 70-1 (Army Research, Development, and Acquisition) or DA Pam 70-21 (The Coordinated Test Program). These publications rarely deal with the unique or unusual systems which create the greatest need for criteria. A possible solution to the difficulty in developing criteria for these systems, and in general most systems, is an active criteria development process. The operational capability objective (OCO) specifies particular needs; however, it does not specify the criteria or measures for assessing the ability of the system to meet those needs. The operational tester, three or more years after the OCO, all too often finds that the user is still unable to further quantify his needs. This deficiency in sufficiently quantifying the user's needs is caused by the relatively passive manner in which the needs are monitored and revised during the time between the development of the OCO and the development of the independent evaluation plan. A continuous process of

refinement and trade off of user needs should occur as the operational factors (threat, tactics, doctrine, etc) change. Changing criteria once they have been established seems to engender a negative connotation. The inference is that a proposed change in criteria is an attempt to fit the criteria to the product (system). While this is possible, a properly managed product assurance program, such as that established for RAM, would reduce the probability of such an occurrence. The RAM program requires an audit trail of essential RAM and support parameters. Such a trail provides not only control but also an incentive to develop better criteria earlier in the system development process. The early identification of requirements is essential in future testing.

In the 1980's, the test and evaluation of unique and new systems in the materiel acquisition process will use models less applicable than those in vogue today, and current systems less equivalent in operational capability. We, therefore, in the testing community are being pressed for deriving new means for providing the decision maker our findings on the military worth and utility of systems. A solution is criteria based on prescribed standards. The Army community must provide quantifiable, realistic, and testable criteria which relate directly to the decision at the level where the decision is required.

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TITLE: Proposed Mechanized Infantry Combat Vehicle Firing Port Weapon Target Engagement Test and Analysis

AUTHOR: Mr. Eugene D. Heiss

ABSTRACT: The Mechanized Infantry Combat Vehicle (MICV) Firing Port Weapon (FPW) will allow infantry squad members to engage the enemy while protected by the armor of the vehicle. In order to determine the FPW's hit capability, a target engagement test will be conducted as part of Developmental Test II. Through the use of new instrumentation, data obtained from this test will be used to estimate the hit capability for targets other than those tested. Using the hit capability, the contribution of the FPW to the success of the MICV mission will be determined.

PROPOSED MECHANIZED INFANTRY COMBAT VEHICLE FIRING PORT WEAPON TARGET ENGAGEMENT TEST AND ANALYSIS

MR. Eugene D. Heiss
U.S. Army Materiel Systems Analysis Activity

The Firing Port Weapon of the Infantry Fighting Vehicle will allow the infantry soldier within the vehicle to participate in the battle while he is protected by the armor of the vehicle, (Viewgraph 1).

The Firing Port Weapon was originally conceived as an inexpensive add-on feature to the Mechanized Infantry Combat Vehicle, (Viewgraph 2). The Cal .45 M3 Submachinegun was first considered for this role. However, the user required a weapon with more penetration and lethality than the Cal .45 Cartridge could provide. Therefore, the M16A1 Rifle was modified for this role, (Viewgraph 3). These modifications are: (Viewgraph 4).

As the Firing Port Weapon does not possess a sighting system, fire is brought to bear on the target through the use of tracer ammunition. The target engagement test of the Development Test II will consist of firing at three equally spaced "E" type silhouette targets, (Viewgraph 5), located at ranges of 50, 100, and 200 meters from the vehicle. Firings will be conducted from both a stationary and a moving vehicle. Each engagement will consist of firing twelve rounds (stationary vehicle) or thirty rounds (moving vehicle), in short bursts.

Due to the necessity of estimating the hit capability for targets and ranges other than those tested it is necessary to obtain an estimate of the system dispersion. The projectile coordinates are used in an attempt to estimate these system dispersions. The method of engagement and the large system dispersions anticipated with this weapon make it necessary to consider other than standard methods of obtaining these coordinates. At the time that instrumentation was being considered, both the Cal .45 M3 Submachinegun and the Modified M16A2 (XM231) were to be tested. For weapon comparison evaluation it was decided that the same instrumentation would be used to obtain the projectile coordinates for both weapons. The only instrumentation which would allow this and also have the capability to obtain the projectile coordinates of all of the rounds fired in a burst was a hit sensitive panel, (Viewgraph 6).

By constructing the panel of overlapping horizontal and vertical strips the position of the projectile on the panel will be obtained to within 5 cm. The following data will be obtained from this test: (Viewgraph 7). These data will be used to obtain the following estimates: (Viewgraph 8). These estimates will be used in the determination of hit capability (Viewgraph 9). The probability of hit per burst will be determined using the three-distribution machinegun mathematical model (Viewgraph 10). The probability of the first projectile of a burst hitting a target is determined by the distance the center of impact of the first projectile is from the target and the dispersion of the first projectile.

The contribution of the subsequent projectiles to the hit capability of the burst is determined by assuming that the subsequent projectiles of the burst are distributed separately from the first projectile (Viewgraph 11). The center of impact of the subsequent projectiles is offset from the first projectile by a value whose mean is XBO (YBO) and standard deviation is SXO (SYO). The subsequent projectiles in a burst are distributed about their center of impact by the standard deviation SXS (SYS).

The hit capability of the Firing Port Weapon will be used to determine the capability of the Firing Port Weapon to fulfill its mission profile and contribute to the performance capability of the IFV. The targets included within this mission profile are an RPG team, trucks, bunkers, and exposed personnel located from 50 to 300 meters from the vehicle.

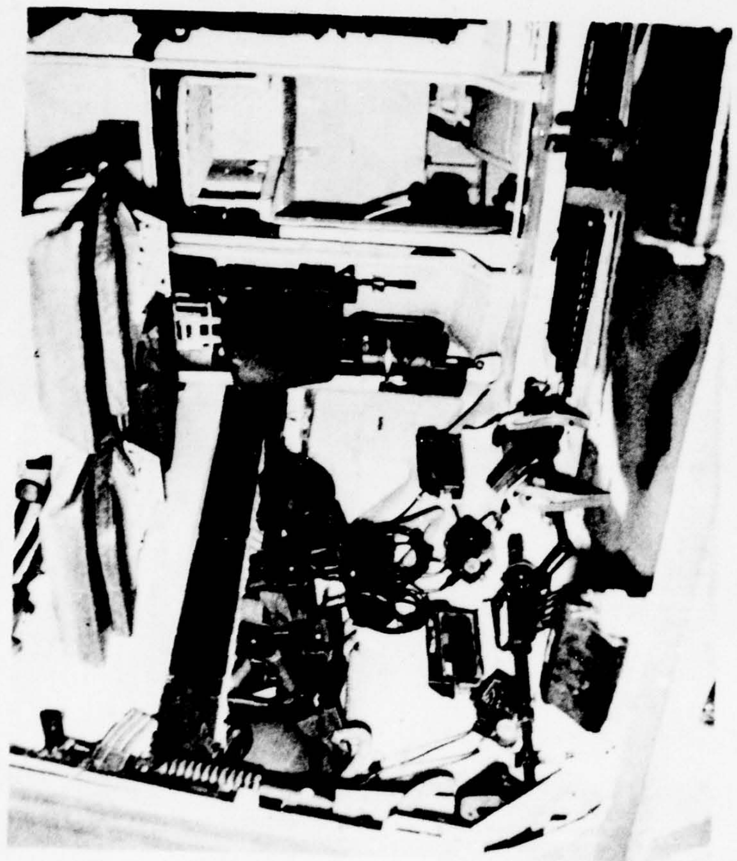
MICV SYSTEMS

MICV TBAT II

377 22

MICV SYSTEMS

MICV TBAT II
Interior



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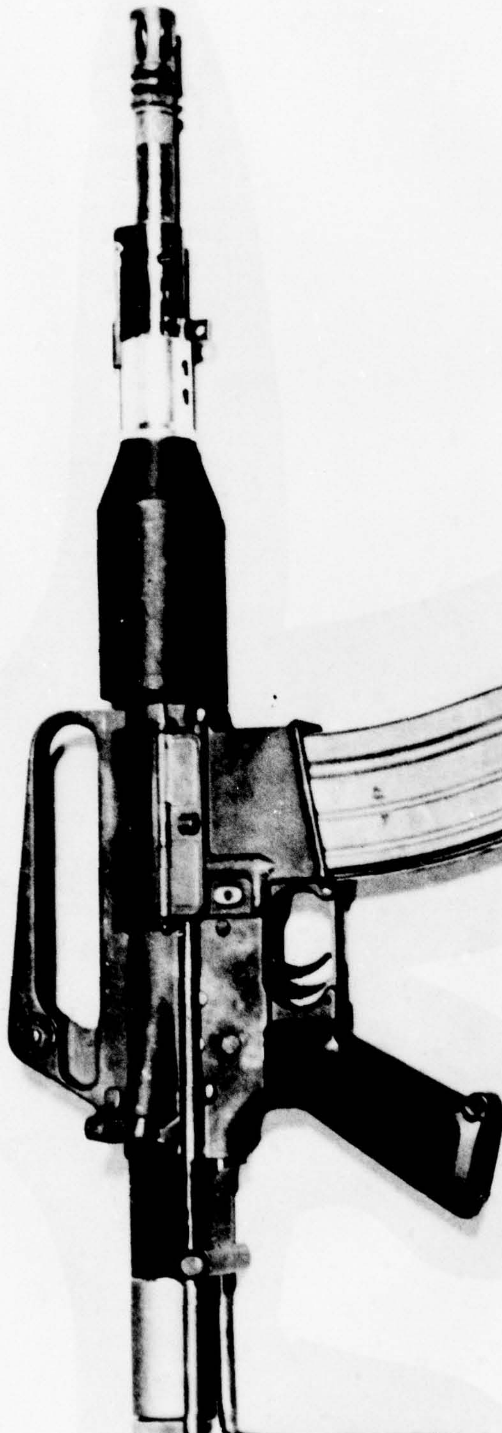
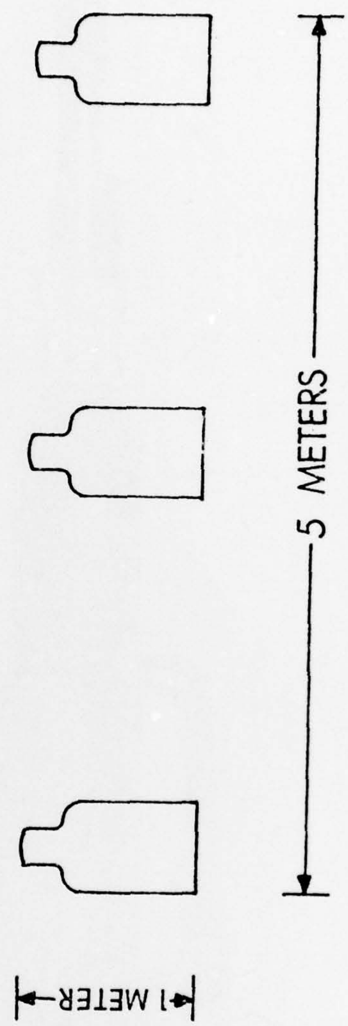
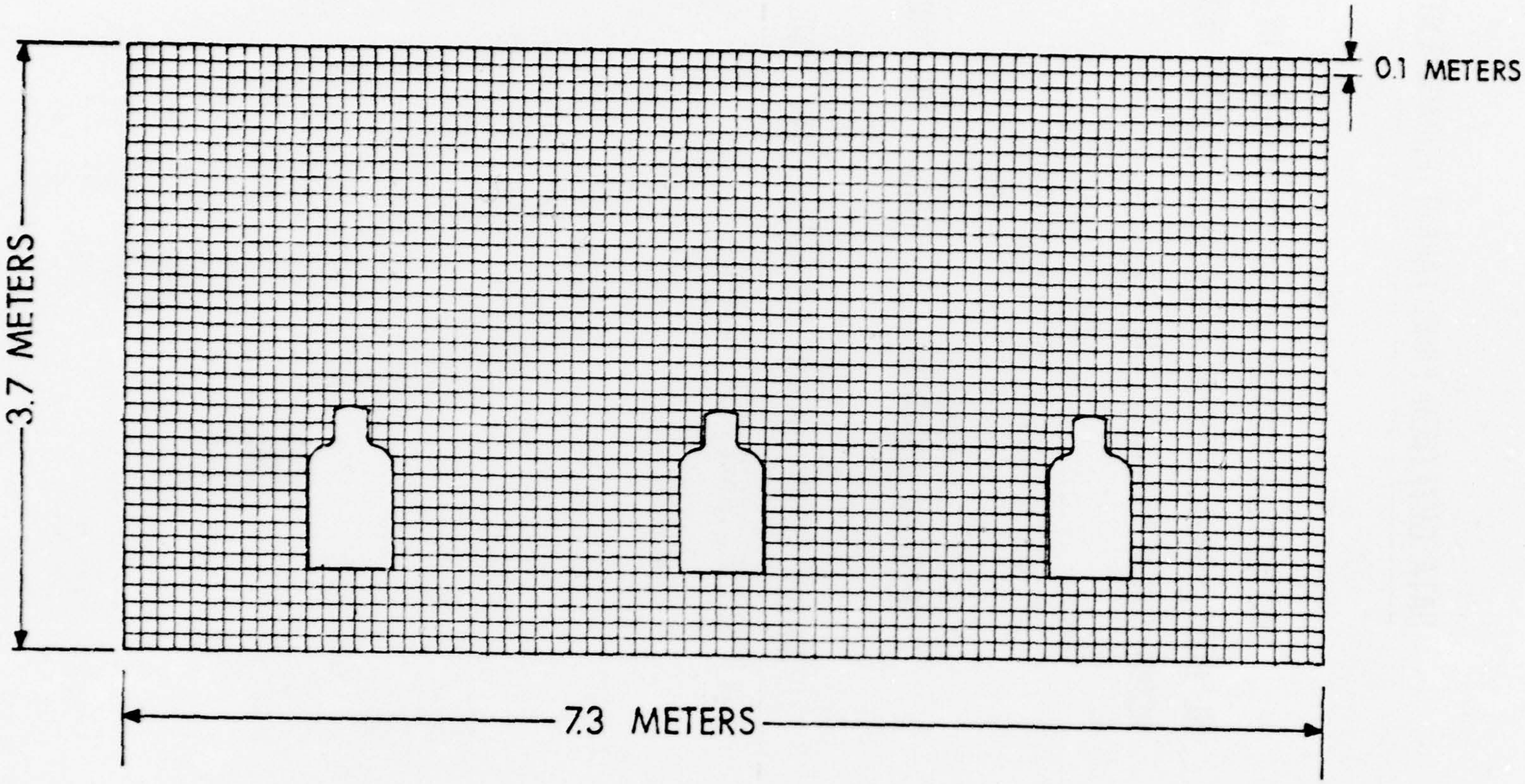


MICV FIRING PORT WEAPON TARGET ARRAY



HIT SENSITIVE PANEL



DATA OBTAINED FROM TARGET ENGAGEMENT TEST

PROJECTILE COORDINATES IDENTIFIED BY ENGAGEMENT NUMBERS, BURST NUMBERS WITHIN THE ENGAGEMENT, AND ROUND NUMBER WITHIN THE BURST

TIME EACH ROUND IS FIRED

TIME EACH ROUND HIT THE TARGET OR PANEL

WHICH ROUND IN THE ENGAGEMENT HIT ONE OF THE SILHOUETTE TARGETS, IF ANY

ESTIMATES OBTAINED FROM TEST DATA

MEAN AND STANDARD DEVIATION OF THE FIRST ROUNDS OF THE ENGAGEMENT

STANDARD DEVIATION OF THE IMPACT POINTS OF THE SUBSEQUENT ROUNDS OF A BURST

MEAN AND STANDARD DEVIATION OF THE DISTANCES FROM THE FIRST PROJECTILE TO THE CENTER OF IMPACT OF THE SUBSEQUENT PROJECTILES

MEAN AND STANDARD DEVIATION OF THE TIMES TO FIRST BURST AND TIMES BETWEEN BURSTS

HIT CAPABILITY DETERMINATIONS

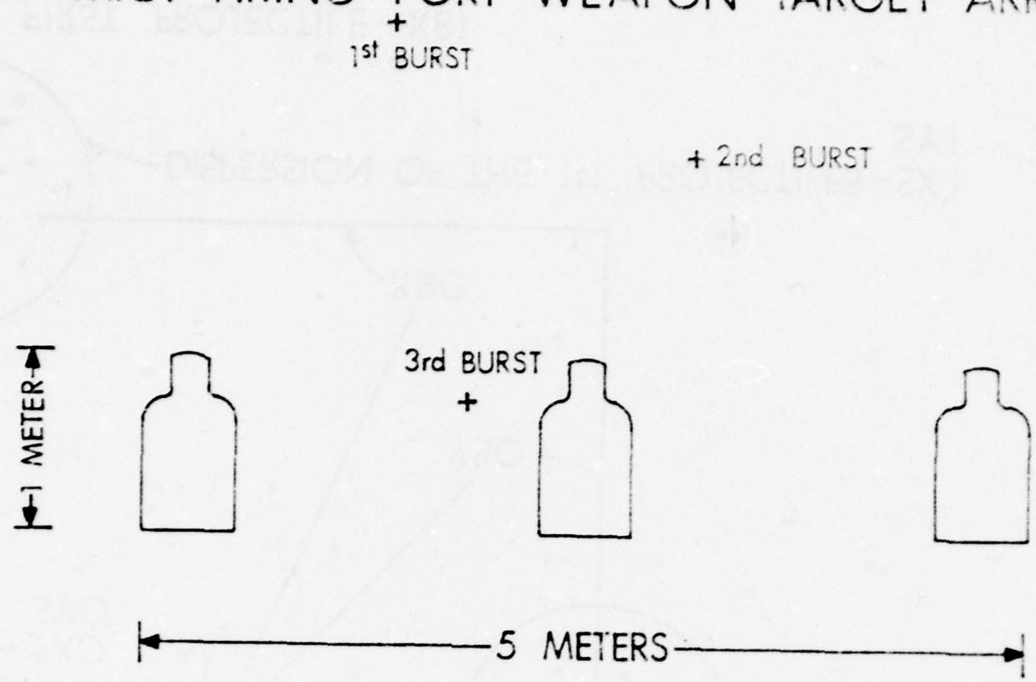
PROBABILITY OF AT LEAST ONE HIT ON ONE OF THE THREE SILHOUETTE TARGETS AS A FUNCTION OF TIME

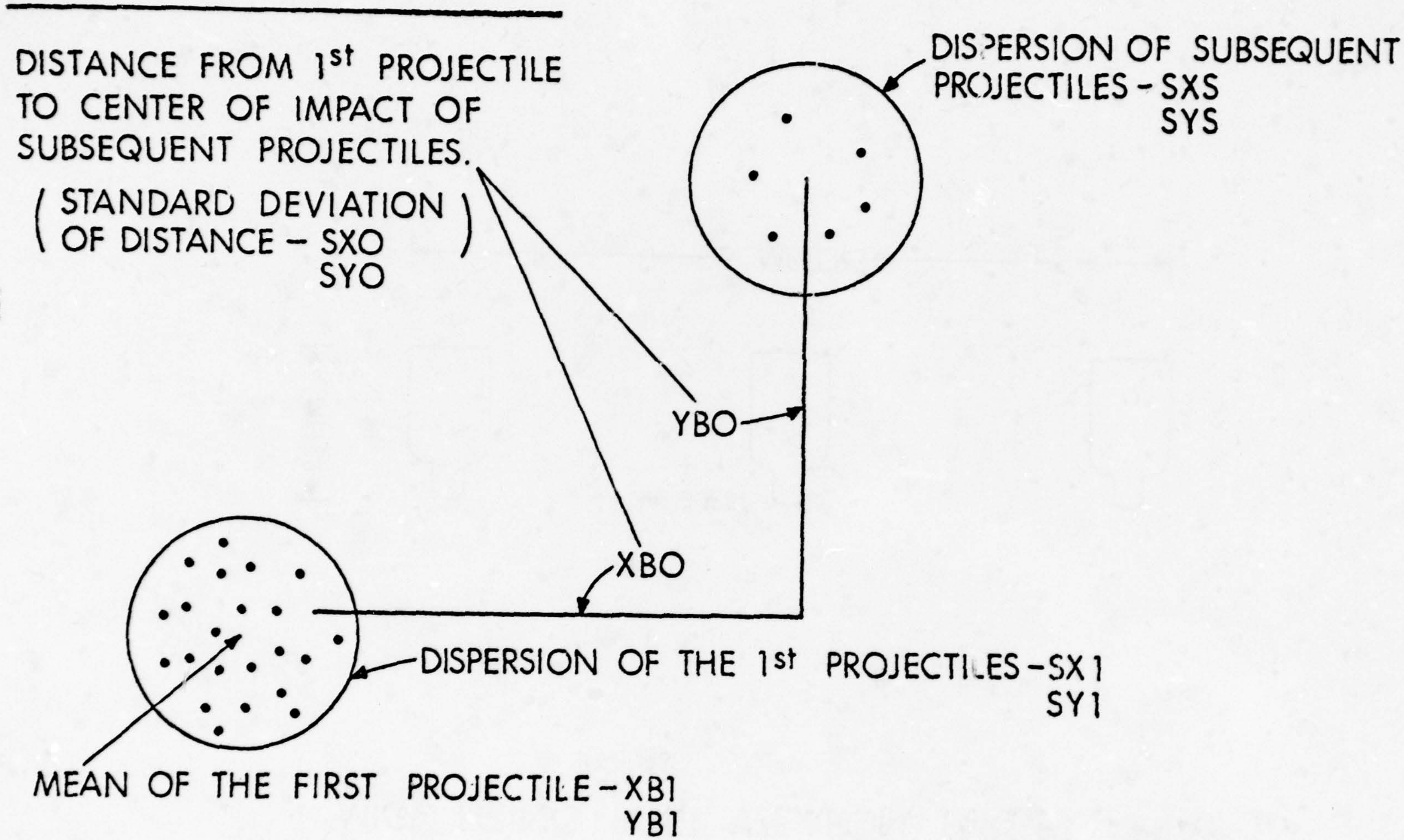
- FOR THE FIRST BURST OF AN ENGAGEMENT
- FOR AN ENGAGEMENT

PROBABILITY OF HIT AS A FUNCTION OF TIME FOR FIRING AT

- TWO-MAN RPG-7 TEAM
- TRUCK CAB
- BUNKER (APERTURE)

MICV FIRING PORT WEAPON TARGET ARRAY




DISTANCE FROM 1st PROJECTILE TO CENTER OF IMPACT OF SUBSEQUENT PROJECTILES.
(STANDARD DEVIATION OF DISTANCE - SXO SYO)
DISPERSION OF SUBSEQUENT PROJECTILES - SXS SYS
YBO
XBO
DISPERSION OF THE 1st PROJECTILES - SX1 SY1
MEAN OF THE FIRST PROJECTILE - XB1 YB1

TITLE: Use of Prime Numbers in a Queuing Simulation

AUTHOR: Michael E. Neyer, U.S. Army Tank-Automotive Materiel Readiness Command

ABSTRACT: Even though prime numbers have always intrigued people, they have found little application outside of abstract mathematics. Recent developments have pointed out the usefulness of primes in generating almost indecipherable codes. Presented here are a few more prime number applications.

For the analyst bothered by random number generators that take up large amounts of computer core or have fairly short periods, try a random number generator that on an IBM 360 uses only 1000 bytes of storage and can generate approximately 1000 random numbers per second for 13 million years before exhausting the period of the generator.

For the analyst presented with the problem of modeling a system of ever increasing factors of ever decreasing significance, relief may be found in using the pattern of prime numbers in an interval determined from the probability of an occurance of a system success. This could be used to simulate kills in tank artillery and anti-tank rockets.

For the analyst beset with trying to find a random number generator with cyclic undertones, as in modeling a requisitioning process, the intervals between primes nicely simulate such a process.

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THE 13 MILLION YEAR RANDOM NUMBER GENERATOR

A random number generator of extremely long period can be constructed in the following manner:

Define: S_i = ith series

C_i = period of S_i

$S'_i\ (n) = S_i\ (n \text{ modulo } C_i)$

If $S_i(n) = 1 + (n \times k)$ Modulo C_i

where C_i and k are relatively prime

then $S'_i\ (n + 1) = S_i(S'_i\ (n))$.

The random number generator R is defined as:

$R\ (1) = \Sigma S_i(1)$

$R\ (n) = \Sigma S'_i\ (n)$

R has the following properties:

C_r = LCM (C_i) or ΠC_i when all C_i are relatively prime

$\mu_r = \Sigma_{\mu i}$

$\sigma_r^2 = \Sigma_{\sigma i}^{\ 2}$

If the number of series added together is greater than ten then the distribution of R approaches normal.

The distribution of R modulo C_i is a uniform distribution, for any C_i or factor of C_i.

The 13 million year generator uses the following periods:

100, 47, 43, 41, 37, 31, 29, 23, 19, 17, 13, 11, 7, 3

$C_r = 4.7 \times 10^{18}$

$\mu_r = 217.5$

If you desire a shorter period, use fewer series in the sum. However, this process is useful in that now you can generate a random number evenly distributed over any period T by making a $C_i = T$. For a small σ_r^2, use C_i equal to a prime number, and for a larger σ_r^2, use C_i equal to a product of primes. In either case, the period would remain the same; but the second generator would require more storage.

THE PRIMES THEMSELVES

At this point it becomes necessary to define new terms in order to facilitate formulation of the distribution of primes.

Q = the set of all prime numbers ordered such that $Q_i < Q_{i+1}$.

Read ε as "is an element of."

The probability P that a number is prime is:

$$P(n\varepsilon\ Q) = \prod_{i=1}^{d} (1 - \frac{1}{Q_i}) \text{ where d is constrained by } Q_d^2 < n < Q_d^2 + 1$$

The interval B between primes is defined as:

$$B_i = Q_{i+1} - Q_i$$

$$P(B_i = J) = P(Q_i)\cdot(1 - P(Q_i))^{J-1}$$

$$= e^{J\ln(1 - P(Q_i))} \left(\frac{P(Q_i)}{1 - P(Q_i)}\right)$$

This shows the similarity between primes and the exponential distribution remembering that the distribution of primes is discreet and the factor $P(Q_i)$ is not constant.

If you want to increase the probability of finding prime numbers, you can resort to using a linear integer function $n = ak + 1$. The probability is now

$$P(n\varepsilon\ Q/n = ak+1) = P(n\varepsilon\ Q)/\Pi(1 - \frac{1}{Q_i}) \text{ where } Q_i \text{ is a prime factor of } k.$$

Another way to adjust probability is to look for more than one prime at a time. The probability of all elements of an n-tuple being prime given the n-tuple is of the form $G(a) = (ak + b_1,\ ak + b_2,\ \ldots,\ ak + b_n)$ where all b_i are relatively prime to k.

$$P\ (G\ (a)\ \varepsilon\ Q) = \prod_{j-m}^{d} (1 - \frac{n}{Q_j}) \text{ where } Q_d^2 < ak + b_n < Q_d^2 + 1$$

$$\text{and } Q_m < (b_n - b_1 + 1)/2 < Q_m + 1$$

$$\text{and } k = \prod_{j-1}^{m-1} Q_i.$$

also Q_m must be greater than n

With these formulae in hand, we can start working on modeling.

In the interval 52441 to 78961 P (n ε Q) = .10 with close to 2600 numbers being prime. Setting time (0) = 52441 you would expect to have one success every 10 time intervals.

Using n = 2 x + 1 P (n ε Q) = .20, expected numbers of primes = 2600 and expected time to success = 5

Using n = 6 x + 1 P (n ε Q) = .30, expected number of primes = 1300 and expected time to success = 3.3

Using $(6\ a + 5_1,\ 6\ a + 7)$ for 361 < n < 529

$$P\ (G\ (a)\ \varepsilon\ Q) = \frac{405}{1729} = .23$$

Expected numbers of prime pairs = 6
Complexity factor = 6
Expected trials to a prime pair = 4.5

These examples show the latitude you can use to generate a series of numbers with the desired probability of finding a prime number of n-tuple.

Even if you cannot justify using prime numbers in an actual simulation, it is conceivable that you may wish to use primes as a test for your model under adverse conditions.

ABSTRACT

TITLE: SCATTERABLE MINES: EVALUATION, DEPLOYMENT, AND DETECTION

AUTHORS: CPT Manfred Benkel, Federal German Army, Naval Postgraduate School, Monterey, CA 93940

Dr. Samuel H. Parry, Department of Operations Research, Naval Postgraduate School, Monterey, CA 93940

Modern warfare and changes in doctrines have caused increased emphasis on antitank weapon systems. These changes have been strongly influenced by the advent of scatterable mines. The paper includes a description of the behavior of tanks within minefields which is composed of the task of detecting mines, the detection distance and the associated distribution, the lateral detection of mines, the search distribution and limitations of evasive maneuvers. The specific methodology employed to demonstrate and test the underlying assumptions, as well as special human factors considerations, are discussed. Finally, results and conclusions from execution of the models are presented, indicating the potential use of these results in two-sided land combat models.

SCATTERABLE MINES: EVALUATION, DEPLOYMENT AND DETECTION.

by

Dr. Samuel H. Parry, Naval Postgraduate School
Manfred Benkel, Captain, Federal German Army

I. INTRODUCTION

The enormous build-up of land forces in the eastern part of Central Europe has caused increasing concern among NATO members in recent years. Especially, the ratio of Warsaw Pact tanks versus NATO tanks is constantly increasing.

The development of highly sophisticated anti-armor weapon systems, as well as the improvements which were achieved in the tank sector, led to the negligence of landmine warfare. The reason for this disregard can be found in the way that mines were dispersed, recorded, activated and later, if necessary, cleared. The evolution of scatterable mines, their fast delivery by several means and their self-activating and deactivating capabilities enables the tactical commander to use the terrain as long and early as necessary. The evaluation of the behavior of tanks in a minefield and the determination of the parameters invoved are the basis for a simulation, which was designed to provide a quantitative answer to the saturation density of a minefield.

II. THE BEHAVIOR OF TANKS WITHIN MINEFIELDS

Although it is known that the behavior of tanks while crossing a minefield can be described in detail, it is also known that it is impossible to fully portrait this situation since there are many human decision processes involved which are subject to chance. Thus, the key components of this decision processes are presented.

A. THE TASK OF DETECTING MINES

The first problem to be addressed is the question of which member of the tank crew normally detects a charge. Since barriers are normally controlled and covered by defending elements supported by artillery fire, it is assumed that the enemy will cross the minefields in the buttoned-up mode. This implies that only the tank commander and the driver are involved in the task of detecting mines. However, the commander is predominantly occupied by observing the battle area rather than trying to detect mines. On the other hand, he is the first one to be informed of a minefield emplacement via the communication circuit at company level if another tank hits or detects a mine.

Even if the tank commander happens to detect a mine before the driver does, this information may not be usable by the driver. The reason is either that the driver is already concentrating on a detected mine and may thus be diverted from avoiding this explosive charge or the time available to communicate the exact location to the driver is too short. The detection of a mine requires its

identification, the ability to exactly describe the location, passing this information to the driver who in turn has to confirm the emplacement to ensure that both commander and driver are dealing with the same mine. Furthermore, after having gone through the above process, the driver has to make the decision as to whether he has to take any action to avoid a hit. The time required to perform all these necessary actions before any reaction is prompted may be too long and can easily be demonstrated by computing the distance travelled for a specific speed by defining the length of the process. Therefore, it can be justified that the task of detecting mines is done by the driver only.

B. DETECTION DISTANCE

That distance in front of a tank at which a mine was first recognized is called the detection distance. As explained later in this section, there are two major areas which influence the probability of detection: terrain condition and human factor related influences. Of these two, the terrain conditions will dictate the detection distance.

In the buttoned-up mode, the vision block of the tank driver is characterized by a dead space of 6.75 meters (in case of the Russian T-62) immediately in front of the tank and limitations to the sides. Under perfect conditions, (i.e., flat terrain and no obstacles in the line of sight), the driver's ability to observe the area may encompass a rather long distance. However, even though a mine could possibly be detected far in front of the tank, it seems reasonable to assume that the tank driver is more concerned with the area in the immediate near distance. In order to acquire data to indicate the range of the vision block, a test consisting of 60 trials was conducted. The tanks used in that test were M-60 tanks, but all derivations will be adjusted to the T-62 as realistically as possible. All tank drivers drove over the test area buttoned-up, the paths of the vehicles were fixed, and the mines were placed at different locations but always within the path of the tank. Therefore, the distance at which a mine detection was announced was strictly a longitudinal measurement, since no deviation in the latitudinal measurement occurred. Also it should be noted that in 36 trials (60%) the mine was dug in, and was placed on the surface in the remaining 24 trials. This configuration is in accordance with the assumption that mines scattered by advanced delivery systems are sometimes buried into the ground, if the condition of the soil or vegetation allows such behavior. On the other hand, where the nature of the soil does not admit a penetration, the mines remain on the surface.

An examination of the data was expected to yield information about the percentage of the undetected mines. This number is clearly influenced by different factors which are explained below. In general, the fraction of undetected mines is determined by

$$(1) \qquad P_{ND} = f(cf)$$

where

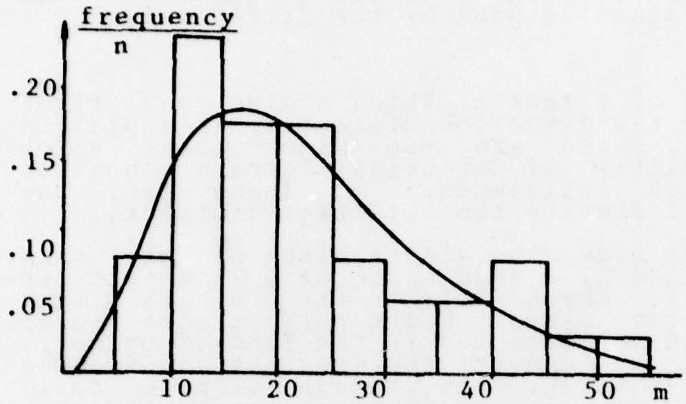
P_{ND} is the probability of no detection

cf is the combined factor under different circumstances and influences.

As further illustration of this concept, it may be stated that for the test described above, no detection was made in 23 of the trials. Thus, P_{ND} in this test is equal to 0.38, regardless of the distance at which the other detections were made.

In general the circumstances by which the probability of no detection is determined can be divided into three categories:

(a) those factors which are related to the combat environment,
(b) those which are based on the personal situation of the soldier involved, and
(c) factors determined by the environment of the battlefield.



The detection distance, given a detection was made, is based on the remaining 37 trials. For data analysis purposes, the following procedure was chosen: The distances at which detections were reported were divided into intervals of 5.00 meters. The first measurements were possible only in the interval from 6.75 meters to 10.00 meters due to the dead space in front of the M-60, which is comparable to the dead space of the Russian T-62. A corresponding histogram is shown in the left figure. Since the histogram indicated that the data may be Gamma distributed, a further investigation was made. First, the parameters of a Gamma distribution (α , β) were estimated from the data by

$$(2) \quad \alpha = (\bar{x})^2/s^2 \quad (3) \quad \beta = s^2/\bar{x}$$

where [x] is the mean distance at which a detection was made and [s] is the corresponding standard deviation.
In the test actually conducted these values were computed to be

$$(2a) \quad \alpha = 3.71$$
$$(3a) \quad \beta = 6.10$$

With these values the Gamma density is given by

$$(4a) \quad f(x) = 0.0003 * x^{2.71} * e^{-0.16393*x} \quad ; \quad x>0$$

Evaluating (4a) at the midpoints of each cell and multiplying the functional value by the cell width yields the values for the Gamma distribution which are superimposed on the histogram.
In order to test the hypothesis that the data can really be approximated by a Gamma distribution, the test statistic was computed. To that test statistic, a Goodness-of-fit test was applied. By combining cells such that the frequencies were always bigger than 5, the test statistic, TS, was evaluated:

$$(4b) \quad TS = \sum_j (f_j - np_j)^2/np_j$$

$$(4c) \quad TS = 1.661$$

The hypothesis that the data are from a Gamma distribution can not be rejected at an alpha level of 0.05 if

$$(5) \quad \chi^2_{k-r-1,\alpha} > TS$$

where

k is the number of cells with frequencies greater than 5.
r is the number of parameters estimated from the data.
α is level of consideration

Since

$$\chi^2_{5-2-1,0.05} = 5.991 > TS = 1.759$$

we can not reject the hypothesis. The procedure was explained in detail in order to allow a reevaluation of the hypothesis if more data are made available.

Another important conclusion from the data set and the derived distribution is the fact that the upper limit of detection distance can be assumed to lie near 55.00 meters. Although the Gamma distribution is unbounded, at a distance of 55.00 meters, 98.5% coverage of the area under the curve is achieved. Therefore, for further considerations the range of detection distance is considered to be sufficiently covered in the range from 6.75 meters to 55.00 meters.

C. LATERAL DETECTION

The distribution of detection distances derived in the previous section is strictly a conditional longitudinal one. The distribution is conditional, because the investigation is based on the fact that a detection was made.
The lateral vision is a function of the distance to the tank and the angle formed by the side boundaries of the vision block. In the case of the Russian T-62 tank, this angle is 48 degrees; it is greater in the case of the U.S.M-60. This fact is indicated by the number of optical vision instruments which are available to the driver: the U.S. model has three, the Russian two.

Discussions with tank drivers who had some experience in driving buttoned-up revealed that the whole field of view is not utilized. If, in fact, the search area does not coincide with the total visual field of view, the question is what shape the search area takes on. First, this area includes the tank width, normally well known to the driver. On either side, an additional margin is added based on certain factors which are partially related to the driver and to the tactical situation. The more experienced the driver, the better his feeling for the width of the vehicle. The additional margin, therefore, is a function of the driver's experience.

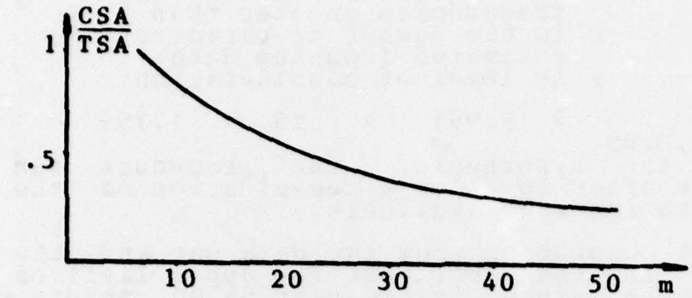
This margin is also influenced by the kind of fuzes installed in the mines. Upon detecting a minefield, one of the most urgent items of information to be gathered is the kind of mines spread in the barrier. Traditional pressure activated mines may limit the driver's attention to the width of the vehicle; in this case the margin is degraded to zero. If electromagnetic fuzes are installed, the margin will be increased and may be overlapping the zone which is dependent on the driver's ability. It can be concluded that the critical search area (CSA) on which the tank driver is concentrating is approximated by a rectangle, the area of which is determined by:

$$A = w * R \qquad (6)$$
$$w = f(tw, e, f)$$

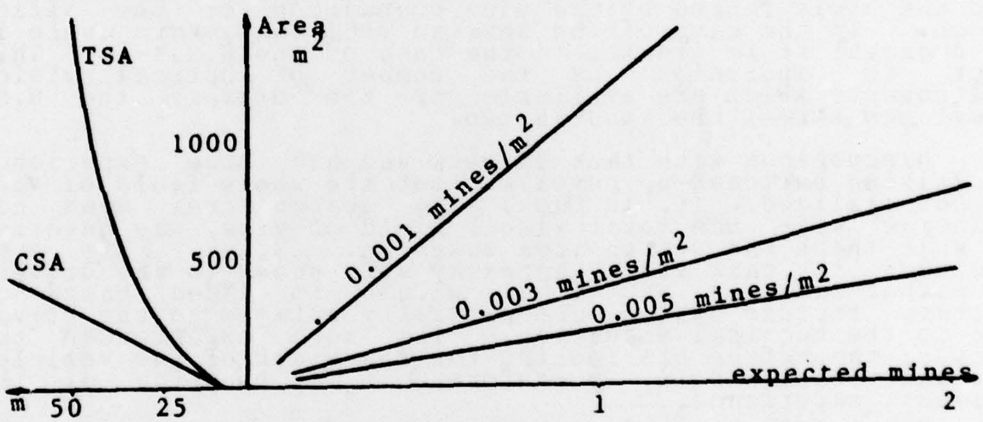
where

R is the range of the longitudinal detection distance
tw is tank width (3.30 m for the T-62)
e is the experience of the driver
f is the fuze installed in mines

The critical search area (CSA) represents a major



improvement versus the total search area (TSA). The magnitude of this improvement based on the distance of the tank can be determined from the figure on the left. The importance of the relation between critical search area (CSA) and total search area (TSA) and the associated improvement is meaningful, especially with respect to human factors involved in the search process and subsequently in the avoidance pattern. The reaction of a tank driver to the detection of a mine is dependent upon the number of mines in the area on which he is concentrating. The most favorable situation would be to have a "one-mine-at-a-time" situation. Although the dispersion of mines within the barrier can result in a local massing, the expected number of mines in the field of view is a good measure of the actual situation. The next figure shows in a graphical presentation the relationship between TSA/CSA and expected mines for different densities at distinct detection distances.

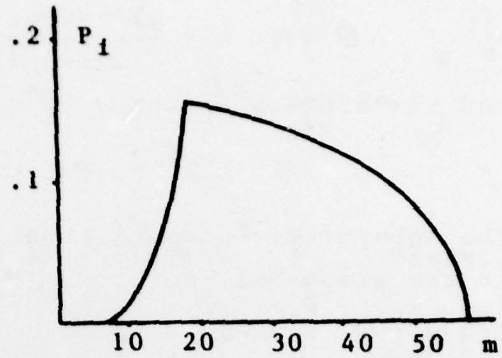


The graph in the above figure also indicates that under the aspect of the critical search area, the expected number of mines ranges from 0.3 mines at the 0.001 mines/meters² density to 1.5 mines at the highest density, assuming the maximum detection distance. Thus, the average situation is described by the fact that the tank driver has to avoid one mine at a time. This value is only exceeded in the case of the highest density with corresponding detection distance greater than 40.00 meters. These results apply only for the width of the critical search area of 6.30 meters.

D. SEARCH DISTRIBUTION

The location of the main area on which the driver is concentrating while crossing a minefield is a function of the speed. The higher this speed, the greater is the distance between tank front and the related area, since the tank driver needs more time to react to a mine encounter. The intensity with which he is looking at the main area does not change with the distance, because the size of the main area remains the same.

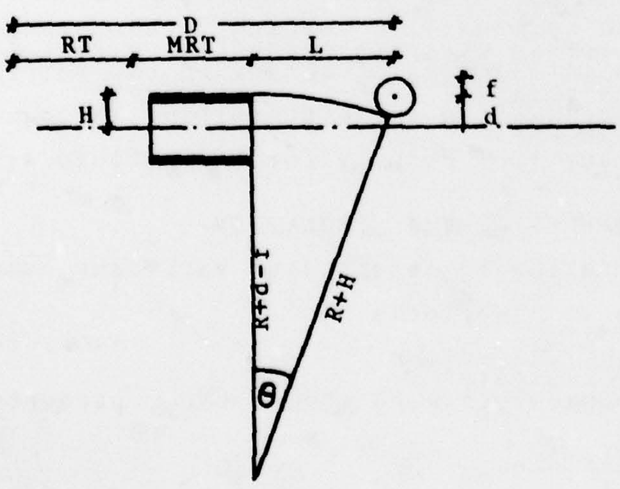
The critical search area and the associated observation limits are known and based on the detection distance derived in section II-B. The geometry of the search distribution is given in the figure on the right. The front of the tank is assumed to be placed at the origin of the coordinate system in this figure. The lower limit [l] indicates the end of the dead zone in front of the tank (l=6.75m). The upper bound [u] defines the end of the critical search area. The location of the peak [m] of the search distribution depends on the speed and the mechanical conditions of the tank to evade a mine in his path. These conditions will be explained in detail in the next section.



The intensity with which the tank driver scans the main sector within the critical search area can be expressed by varying [h] between 0.0 and infinity. A large value of h results in a high probability of looking at the sector including the distance m. Since the search process can be assumed to be almost a continuous one, it can be best approximated by the composition of two parabolic functions as it is shown in the above figure. To determine the probability that the driver is looking at the i-th sector of the CSA, the latter is divided into n sectors of equal length. The area under the composed curve for that sector is computed and divided by the total area, thus yielding the desired probability. It should be noted, however, that the search distribution as demonstrated in the last figure is based on the assumption that the tank driver is experienced in driving, is trained in optimal scanning of the critical search area and knows the evasive capabilities of his vehicle.

E. EVASION MANEUVER

This section examines the conditions under which this avoidance process can be achieved successfully. In the figure to the left a mine detection was made at a distance [D]. This distance is composed of three parts: the driver's reaction time [RT], the vehicle's mechanical reaction time [MRT] and the minimum distance [L]. The minimum distance, L, determines whether the tank can miss the mine for a given speed and maximum lateral acceleration $[a'_1]$. By using the



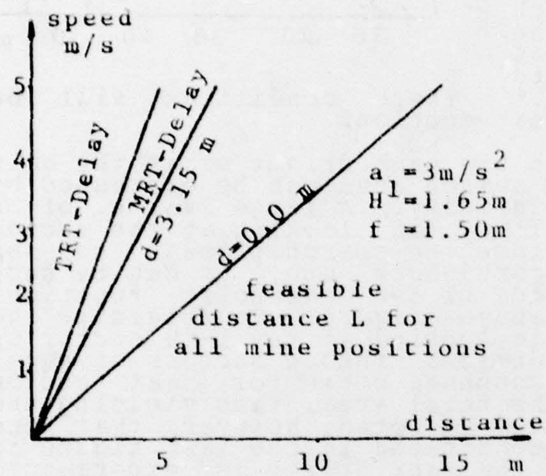
geometric relationship as given in the last figure, it can be show that the radius can be computed by:

$$(7) \quad R = \frac{L^2 + (f-d)^2 - H^2}{2(f-d) + 2H}$$

and the minium distance is given by:

$$(8) \quad L \geq \frac{v^2}{a_1}(2f-2d+2H) - (d-f)^2 + H^2$$

The graphical presentation of the possible minimum distances, L, are given in the next figure. The variables in the graph are the speed [v] and the distance [d] off the centerline where the extreme values for d are indicated to be d = 0.00 and d = 3.15 meters. It should be noted that the values for L given in the following figure emphasize the results of the mean detection distance derived in Section IIB. A mean detection distance of 22.60 meters is always far enough in front of the tank in order to sucessfully avoid a mine and simultaneously maintain a speed between 0.0 m/sec and 7.0 m/sec, which covers the normal interval of cross-country speeds in a combat environment.



III. THE SIMULATION MODEL

Based on the parameters described in the previous sections, a simulation model was developed. This simulation is expected to provide answers to the problems listed below:

(a) How many tanks are necessary, according to the Russian bulling tactic, to clear one path through a minefield?
(b) What is the mean path length of a tank in the barrier before encountering a mine?
(c) How many mines were avoided while travelling through a minefield?
(d) What is the saturation density for a minefield with scatterable mines?

A. THE INDEPENDENT VARIABLES OF THE SIMULATION

For the simulation the following independent variables were chosen:

(1) Configuration of Minefields
(2) Fuze Radius
(3) Density of Mine Dispersion
(4) Level of Detectability

The reasons why those parameters were chosen are presented in the sections below.

1. Configuration of Minefields

It was necessary to consider four distribution patterns:
(a) A uniformly distributed minefield where the mines are

randomly scattered over the area.
(b) Belted Minefield: This configuration assumes that mines are dispersed in lanes within the barrier. The lanes are parallel and have alternating direction of curvature. Three lanes are simulated to demonstrate the dispersion by a unit equipped with M-548's.
(c) Normally distributed minefields with equal standard deviations where it is assumed that the mines are delivered by rocket warheads, each containing 200 mines. Perfect aim is assumed when the impact points for the warheads are fixed.
(d) Normally distributed minefields with different standard deviations are assumed when the Multiple Rocket Launcher System is employed. Each salvo of this system can deliver 180 mines within seconds. The longer standard deviation is along the trajectory and the smaller perpendicular to it.

2. Fuze Radius

If the fuze radius is equal to zero, the mine simulated can be thought of as being activated by pressure or in some other mechanical way. On the other hand, if the fuze radius is greater than zero, other possibilities to ignite the charge are given. Since the additional marigin to the left and right of the tank is fixed at 1.00 meter, a fuze radius of 1.50 meters is chosen to demonstrate the increase in width of the critical search area. Therefore, the fuze radius used in the program is at two levels:

f_1 = 0.00 meters, and

f_2 = 1.50 meters

3. Density of Mine Dispersion

The following densities seem to be reasonable for examination:

d_1 = 0.0005 mines/meter²

d_2 = 0.0010 mines/meter²

d_3 = 0.0030 mines/meter²

d_4 = 0.0050 mines/meter²

4. Levels of Detectability

For simulation purposes the probability of no detection (PROBND) is assumed to be at the following three levels:

0.30 representing high detectability and very good conditions for attacking elements.

0.50 medium detectability; this level describes normal terrain and combat environmental conditions

0.70 less favorable detectability for the attacking elements, since only 30% of all mines in the barrier can probably be detected.

For a full analysis each parameter combination was repeated 10 times; thus, the results of the simulation are based on 960 runs.

B. RESULTS OF MINE ENCOUNTER

As soon as the tank enters the minefield the search for mines is initialized. If there are mines in the critical search area, the appropriate action is taken.

It is important to note that in the simulation the

condtional probability of kill, P_k, given a mine is encountered, is equal to 1.0. Although it is a well known fact that mine encounters do not always result in a total kill, this assumption is necessary since the actual value for P_k is classified. However, adjustments can easily be achieved by multiplying the actual values with the results of the simulation. As an example, assuming for the combination T-62 and mine scattered by the mine dispersion tank M-548 the P_k = 0.5, the result from the simulation that the fourth tank crossed the minefield has to be multiplied by 0.5. Thus, a comparison to reality leads to the statement that the second tank achieved a breakthrough. After a mine encounter, the appropriate mine will be deactivated for that run to prohibit a multiple encounter caused by the same mine.

The next two sections explain the simulation's logic for a mine located in the critical search area.

1. Encounter of a Detectable Mine

After entering the minefield the critical search area is scanned for the nearest mine in front of the tank. An identification number associated with each mine determines whether the mine is detected or not. Given the mine emplacement is outside the dead zone with regard to the current tank position within the barrier and is covered by the detection distance, then the distance between tank and mine necessary to successfully avoid the charge, as well as the corresponding radius, is computed. The avoidance is always done in the more advantageous direction, dependent on the relative mine emplacement to the tank's axis. When the direction of avoidance is determined, the sequence of evading is fixed in direction and radius. The encounter of a mine in the path of avoidance (that is, if a mine is in the area swept by the vehicle from starting the avoidance to completely finishing it) will result in a hit. Under these circimstances, a new tank will be brought into the position of the start of the avoidance process, but will try to evade the mine in the opposite direction as compared to the first tank.

2. Encounter of an Undetectable Mine

As was explained in the previous section, the identification number associated with each mine determines (in comparison to PROBND) the detectability. Whenever this number is smaller than PROBND, the charge is assumed to be undetectable. Whenever the mine located in the immediate front of the tank is undetectable, it will be hit by the vehicle, since no evasive maneuver is possible. In the path of the stricken tank the next one follows, assuming a position so far to the rear of the first tank that an avoidance is possible. Since the decision is left to the tank driver as to which avoidance direction he will take, a Monte-Carlo-Routine determines whether a left or right evasive maneuver is made. In terms of the simulation, moving around a tank is equivalent to avoiding a detectable mine located on the axis of the tank path with a fuze radius equal to half of the tank width.

C. TERMINATION CRITERIA

Three different situations lead to the termination of a simulation run. They are:
(a) Successful Crossing of the Minefield.
(b) Jamming of Two Tanks.

If the tank driver crossing a minefield detects a mine and is able to avoid it, he will take the necessary action to do so. However, during the avoidance process it is possible that another mine will be encountered. That mine can not be avoided, although it may be detectable; thus, a hit occurs. The following tank starts in the same track and at the same location where the former tank began the avoidance process. Whenever there is a mine in the path of avoidance of the second vehicle, it will also be hit.

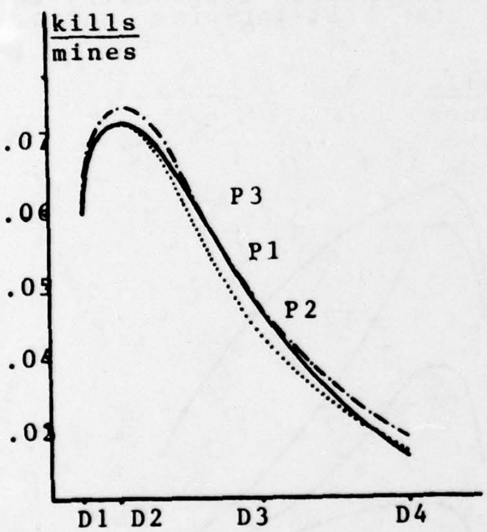
(c) Three tanks will be hit in the same area.

If there is a mine located in the trace of a tank and the mine can not be detected, that charge will be encountered. The following tank starts to move around the first tank at minimum distance and radius. The emplacement of a mine in the path of avoidance results in the hit of the second tank. A third tank tries to move aound the first tank on the alternate side compared to the second one. A mine encounter in its path is also possible. This situation, where three tanks are hit, leads to the conclusion of that specific run.

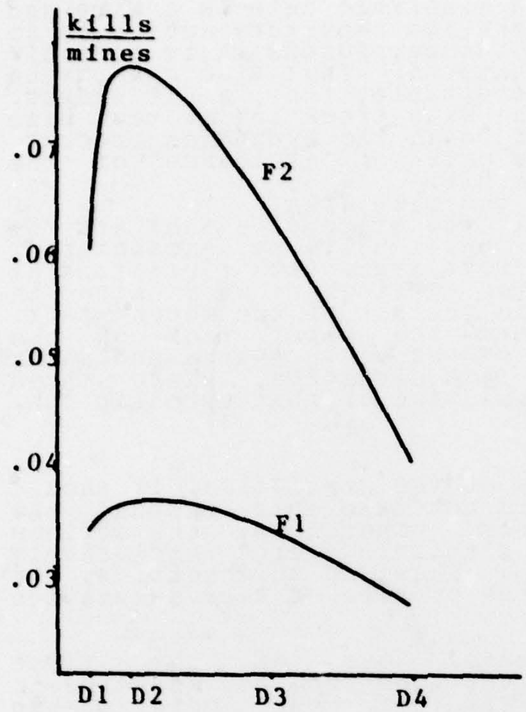
D. RESULTS OF THE SIMULATION

Before interpreting the results of the simulation, it should be noted that the simulation did not take into account the presence of defending elements. Therefore, the actions taken by tanks within the minefield are exclusively reactions to mine encounters. Thus, in this section, the discussion is centered around the problem of the saturation density for minefields.

By investigating the results, one of the first questions to be answered is that of the relationship between the different levels of the probability of no detection (P1, P2 and P3). To show this, the combination of fuze radius (F2 = 1.50 meters) and a belted minefield was chosen. The figure on the left demonstrates how close the individual curves for the three levels of the probability of no detection are. This proximity is the justification for averaging over the probabilities of no detection in following graphs. A further reason for using the average is the fact that in a single minefield, mines are never scattered in such a way that a specific level fits for the whole barrier. There will always exist parts of the obstacle where mines can be detected much easier than in others.

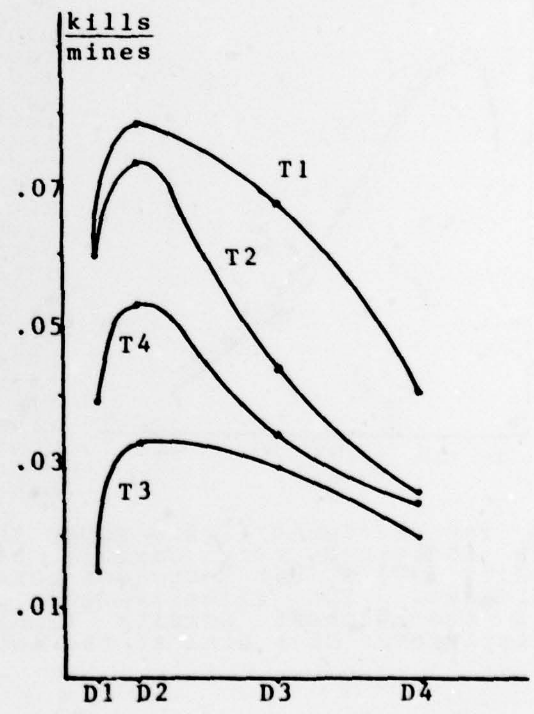


The preceding figure shows that the number of kills per mine increases very rapidly between the 0.0005 and 0.001 density levels, but decreases more and more as the density increases. The effectiveness of a charge in a minefield with the highest density simulated is less than the effectiveness of a mine at the lowest density.

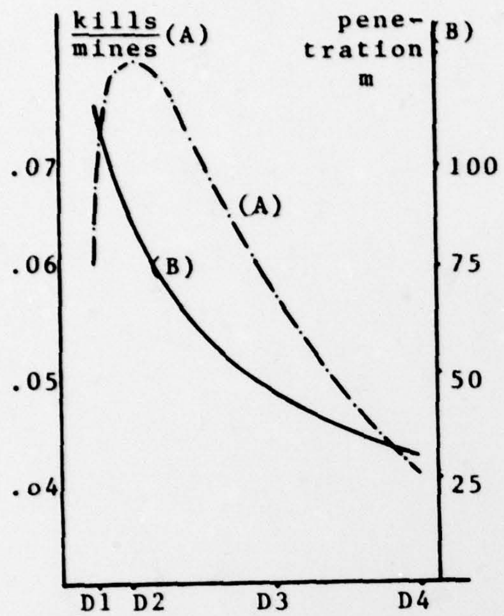


The proximity of the probabilities of no detection at the distinct levels permits averaging over the range from 0.30 to 0.70. This was done to derive the values for the plot to the left where the difference of the two fuze radii is examined. The higher return of kills per mine if the fuze radius is 1.50 meters as compared to a fuze radius of 0.00 meters can be explained by the wider area in which a mine can be encountered. Although the greater fuze radius leads to an enlarged critical search area, the decrease in kills per mine is much greater than in the situation where the fuze radius is equal to zero. Therefore, it can be supposed that increasing the fuze radius does not contribute to an essential improvement in the kill-per-mine ratio.

Since four different minefield types were examined, it was important to compare the returns per mine for each type individually. The figure to the right presents the graphical demonstration for the different minefield types. It should be noted that the values for kills per mine are best if the mines are uniformly distributed over the area. The distribution in belts, although tactically easier to employ, is not as good as the uniform distribution, but better than any of the two normally distributed cases. Surprisingly, the elliptical distribution is more efficient than the circular normal distribution.



The last graph is intended to show the relationship between kills per mine and the penetration depth at the minefield densities in question. To show that relation the parameter combination of minefield type II and fuze level F2 was chosen where the values for the probabilities of no detection were averaged. The last figure shows that for densities less than 0.001 mines per square meter the number of kills per mine increases, while it decreases at higher densities. Simultaneously the penetration into a minefield until a mine encounter decreases very rapidly for lower densities. On the other hand, if the density increases, the slope of the curve representing the mean penetration depth decreases. This means that for densities higher than 0.003 mines per square meter not only the value of kills per mine decreases, but, in addition, the decrease in penetration depth becomes insignificant. This fact supports the statement that at a density of 0.003 mines/meters^2, a saturation is definitely reached.



The importance of the saturation density is based on the resources available to the tactical commander. The supplies with scatterable mines will be even more limited than was the case for traditionally dispersed pressure activated mines, since scatterable mines are much more expensive.

Knowledge of the saturation density enables the commander in charge of the defense to optimize his efforts by dispersion of all resources in one or two barriers at a high density. As an alternative, he may order several minefields at low or medium density.

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